UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DESIGN OF EXPERIMENT (DOE) BASED RESPONSE PREDICTION IN MACHINING

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

JEEVINTHARAN A/L SIVASANKARAN

FACULTY OF MANUFACTURING ENGINEERING

2010

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS TESIS*

JUDUL: **Design of Experiment (DOE) Based Response Prediction in Machining**

SESI PENGAJIAN: 2009/2010

Saya **JEEVINTHARAN A/L SIVASANKARAN**

(HURUF BESAR)

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 1723, Jln RJ 2/8,
Taman Rasah Jaya,
70300 Seremban, Negeri Sembilan.

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	:	Jeevintharan a/l Sivasankaran
Date	:	April 2010

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:

(Signature of Supervisor)

……………………………….

(Official Stamp of Supervisor)

ABSTRACT

Laser cutting has great ability in cutting material and the use of laser cutting become widely in manufacturing field. In this project, the improvement planning is focused on the laser cutting machine parameters. The experimentation purposes are to determine the significant and insignificant factors which influence the quality of a product which manufactured by laser cutting machine and to optimize the machining parameters to obtain best cut quality. Factorial design based optimal parametric analysis has been performed to determine the optimal setting of process parameters for 2.5mm and 5.0 mm mild steel (RST37-2) where the response was surface roughness (Ra). Focal distance, gas pressure, power and cutting speed are the process parameter that was investigated in this study. The lowest and highest Ra value for 2.5mm mild steel that obtained was 1.69 µm and 11.09 µm. As for the 5mm mild steel lowest and highest Ra value that obtained was 2.25µm and 19.82 µm. From the analysis, cutting speed and gas pressure has significant effect to the surface roughness for 2.5mm mild steel. Meanwhile cutting speed, gas pressure and power has significant effect to the response surface roughness for 5 mm mild steel. A set of mathematical model for each 2.5mm and 5mm mild steel cutting process has been established with the aid of Balanced ANOVA analysis to generate the best optimize value of process parameters..

ABSTRAK

Kaedah pemotongan material menggunakan pemotongan laser mempunyai kelebihan tersendiri dan penggunaannya kini semakin meluas terutamanya dalam sektor pembuatan. Dalam projek ini, perancangan pembaikan adalah tertumpu kepada parameter mesin pemotongan laser. Tujuan eksperimen ini adalah untuk mengenalpasti parameter yang paling mempengaruhi dan yang tidak mempengaruhi kualiti produk yang dihasilkan daripada pemotngan laser dan juga untuk mengoptimumkan parameter pemesinan untuk mendapatkan quality pemotongan yang baik. Kaedah factorial design digunakan untuk menentukan process parameter yang optimum bagi 2.5mm and 5.0 mm besi lembut (RST37-2) terhadap respon (surface roughness, Ra). ‘Focal distance’, ‘gas pressure’, ‘power’ dan ‘cutting speed’ adalah parameter proses yang telah dianalisis. Nilai Ra paling rendah dan tinggi yang diperolehi bagi 2.5mm besi lembut adalah 1.69µm dan 11.09µm. Bagi besi lembut 5mm nlai Ra paling rendah dan tinggi yang diperolehi adalah 2.25µm dan 19.82µm. Daripada analisis, ‘cutting speed’ dan ‘gas pressure’ adalah parameter proses yang paling menunjukan kesan terhadap respon (surface roughness) bagi besi lembut 2.5mm. Sementara itu, ‘cutting speed’, ‘gas pressure’ dan ‘power’ adalah parameter proses yang paling mempunyai kesan terhadap respon (surface roughness) bagi besi lembut 5mm. Satu set formula matematik masing-masing bagi besi lembut 2.5mm dan 5mm dihasilkan dengan bantuan analisis ‘Balanced ANOVA’ untuk mendapatkan nilai optimum bagi setiap parameter proses.

ACKNOWLEDGEMENT

First and foremost, I would like to dedicate my deepest gratitude to my supervisor, Ir Sivarao a/l Subramonian for the supervision along the time I was doing this project. I really appreciate his advice and valuable guidance throughout to course of this project.

I wish to extend special appreciation to the laser cutting technicians for their patient, helps, and support to complete this project

I would also like to express my deepest appreciation and gratitude to my family members for their love, sacrifice, motivation and support given during course of this project. Last but not least, I would like to thank those who have contributed directly or indirectly towards the success of this project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANOVA	-	Analysis of Variance
CO_2	-	Carbon Dioxide
DF	-	Degree of Freedom
DOE	-	Design of Experiment
DPSSL	-	Diode pumped solid-state laser
F.D.	-	Focal Distance
HAZ	-	Heat Affected Zone
Hz	-	Pulse frequency
J	-	Pulse energy
J/cm^2	-	Laser energy over area
KPIV's	-	Key Performance Input Variables
KPOV's	-	Key Performance Output Variables
mm/s	-	Cutting speed
N_2	-	Nitrogen
O_2	-	Oxygen
OFAT	-	One Factor-at-a –Time
QFN	-	Quad Flat No-ead
Ra	-	Surface Roughness
RSM	-	Response Surface Method
R^2	-	R-Squared
R-Squared	-	Relative Significance

CHAPTER 1

INTRODUCTION

1.1 Background of the Project

In recent years, experimental design has become very familiar where it had been practically being applied in the big company and factory worldwide. It has been successfully brought rapid improvement to the process that goes through this implementation. If the experimental is well-designed, it can eliminate all possible causes except the one's that been tested. To relate the operating variables and characteristics of the laser to the parameters affecting the cut quality, many models have been developed over the years for the laser cutting process. Modeling provides considerable insight into the interaction mechanisms.

The need to establish the laser processed parts that satisfy all functional requirements of the application as a uniform surface finish, low roughness and the conservation of their metallurgic properties was the main motivation in the accomplishment of this study. Besides the versatility and advantages, as well as the industrial sector global trend, became important factors in the lasers use as machining tools. The scope of present study was to investigate the effects of laser processing on the quality and formation of phases in the cut surface. A factorial arrangement regarding the several combinations of different processing factors is built and the influence of these specific parameters, which were statistically significant for the process, was evaluated by the analysis of variance statistical test.

1.2 Problem Statement

Industries which inserted in the production chain aims at continue enhancement on their processes control and also on their products development. Factors such as quality, reliability and costs reduction are important motivations for the operational excellence achievement serving also to generate competitive items in the global scenario. Consequently, these factors may be the basis of choosing the laser processing replacing the conventional methods. This procedure includes several segments in different areas where the laser is focused by the main industrial applications such as cutting, drilling, welding, thermal treatment and marking.

The applications for the laser material processing involves mechanisms on which it becomes necessary to adequate the type of material and its geometrical shape to the laser type (which is determined by the wavelength and the continuous or pulsed operation mode). From this selection it is also necessary to choose and set the various process parameters that influence on the final result such as quality, cost and speed, among others factors. This technology stimulates major interest due to the fact that it joins various advantages such as: non contact process and no tool wear, possibility of using a controlled atmosphere, high energy density, flexibility on the beam delivering, simplicity in fixation, easy automation, small heat affected zone, high speed, excellent edge quality.

Laser cutting is being a popular process in most manufacturing industries nowadays. Both metallic and nonmetallic materials are cut, welded, and surface treated by different types of lasers at different operating powers. This paper aimed to study the capability of low power laser to perform several tasks other than marking. A theoretical model was developed to estimate the depth of cut with the cutting speed and laser power for different materials. The agreement between theoretical and experimental results will be investigated for different range of materials. A semi-empirical equation was introduced either to assist optimize the cutting process or to determine the required capacity for the selection of the laser machine.

Laser cutting is probably the most widely used laser processing technology. It can produce good quality product with faster machining process and this advantages make the requirement of it in manufacturing field increase. But, there are still few weaknesses about this machine, where it results in high cost and high maintenance.

This machine consists of some common components or parameters that always used during the part producing. All these machine parameters contribute and influence the quality of the product that being produced. But, the levels of influence for each parameters are different where there are some parameters that greatly influence the output or quality of product which significant to the process. There are also some machining parameters that which less influence the machining process and the quality of the product where if these parameters are neglected the quality of the product won't be much effected by it. In this condition, the insignificant parameters can be illuminated in order to prevent the cost and time wastage.

Then, there must be some kinds of analysis to determine which parameters are not contribute much and which parameters are the significant factors in the machining process. Mathematical modeling in laser cutting is essential to improve the understanding on the process. A variety of overviews have appeared over the last decade, with guidelines and data for laser cutting of various types of materials. Additional modeling endeavors have extended the level of analysis to incorporate other factors such as reactions between the assist gas and cutting front, and dynamic effects of striation formation. The variation of material absorptive is also an important factor in laser cutting for which some investigations have been conducted in recent years. The modeling of laser cutting generally attempts to evaluate the cutting quality for given conditions or to estimate the cutting capability for a given laser and material.

1.2 Project Objective

The uses of DoE nowadays become widely in not only in manufacturing industry but also another industries including food industry, aerospace industry and etc. It was accepted that DoE method is an effective method to control the relationship between input parameters and the output variable. For this project the main objectives are as listed below.

i.) To observe the function and the effectiveness of DOE based response prediction in laser machining.
ii.) To determine the most significant parameters in laser machining.
iii.) To optimized the machining parameters to obtain best cut quality.

1.3 Project Scope

We are concerned with the analysis of data generated from an experiment. It is wise to take time and effort to organize the experiment properly to ensure that the right type of data, and enough of it, is available to answer the questions of interest as clearly and efficiently as possible. This process is a type of experimentation which called experimental design. There are many types of experimental design that are commonly used and in this study it was focused on the Design of Experiment (DOE) which are highly proved in producing accurate determination of the process analysis improvement.

This project carried to design an experiment for the metal machining for the purpose of determining the significant parameters. The machining process that was conducted was laser cutting. The materials that used are Mild steel, RST37-2 with two different thickness, 2.5 mm and 5.0 mm. After the significant parameter has been identified, the optimization of the significant parameter was made. The analysis is carried out to identify the interaction between the parameter whether the parameters has direct or indirect interaction. In this study, there were four major parameters that have been analyzed. They are Focal Distance (FD), Gas Pressure, Power and Cutting

Speed. These are the major parameters that most likely more significant in laser machining which were identified true previous studies. Finally, from the analysis, the model or equation was established.

In this project the Minitab 14 software was used to analyze the data. The parameters apply on the machining process was analyzed by the software based on Design of Experiment (DoE). In this research, full factorial design is the model which was analyzed in its modeling capabilities. At the end, the mathematical model was derived in order to identify the most effected parameter to the product quality.

For laser cutting machine, there are types of parameter that consist of fixed and variable parameters. In this case, there were some factors or parameters that significant to the machining process which can produce good quality of product and there also parameters that influence the process fractionally only. For variable parameters that not contribute to the process much will be removed from the process compare to the fixed parameter that can't be changed. By eliminating those parameters from the machining process, it can reduce the product's machining cost and the machining time.

CHAPTER 2

LITERATURE REVIEW

The objective of experimental design is to provide the researcher or a practitioner with a statistical method that determined which input variables are most influential on the output and where to set the influential input variables so that the output is either maximized, minimized or nearest to a desired target value. The design of experiment approach can be applied to the objectives that are as follows; smallest-is-the-best, larger-is-the-best or nominal-is-the-best. One of the essential ideas underlying a designed experiment is that some methods of collecting input and output data are more powerful than others. The method of analyzing one input variable at a time, while holding the others fixed, turns out to be the least effective design. In a statistically designed experiment, the practitioner is able to change the much needed and often desired multiple variables to determine the impact of the response.

Although the design of experiment concepts has long been used in the sciences, industry has not caught on with these methods since their introduction in 1940s. In recent years, however design of experiments has gain great popularity, primarily because of its great success in Japan when it was introduced by W.E.Deming [57]. While Sir Ronald A. Fisher [2-4] was clearly the pioneer in the use of statistical methods in experimental design, there have been many other significant contributors to the literature of experimental design, including F. Yates [58-60], R.C. Bose [61], to name a few.

The applications for the laser material processing involves mechanisms on which it becomes necessary to adequate the type of material and its geometrical shape to the laser type (which is determined by the wavelength and the continuous or pulsed operation mode). From this selection it is also necessary to choose and set the various process parameters that influence on the final result quality, cost and speed, among others factors [11] and [27]. This technology stimulates major interest due to the fact that it joins various advantages such as: non contact process and no tool wear, possibility of using a controlled atmosphere, high energy density, flexibility on the beam delivering, simplicity in fixation, easy automation, small heat affected zone, high speed, excellent edge quality.

An attempt to improve such properties surface engineering may cause some difficulties to the conventional machined methods such as: high tool wear, processing time and operational costs. Both metallic and nonmetallic materials are cut, welded, and surface treated by different types of lasers at different operating powers. Coherent [17] reported that a 500 W CO_2-laser was used to cut nylon seat belts. The laser operated at a cutting speed of 20 mm/s. It was also reported that a 275 W CO_2-laser was used with a 254 mm focal length lens and a coaxial gas jet to cut 114 mm thick rubber foam at a speed of 16.6 mm/s. Peters [15] investigated the application of lasers in cutting wood. A 1 kW CO_2-laser was used with an assisted N_2 gas jet. Furthermore, Todd [28] reported that a 560 W CO_2-laser beam can remove ceramic materials at a rate of 5.3 mm^3/s. Numerous theoretical models for laser machining have been development by researchers.

There are still many problems that are not well-understood in laser cutting. Mathematical modeling of laser cutting is essential for improved understanding of the process. A variety of overviews have appeared over the last decade, with guidelines and data for laser cutting of various types of materials [10 and 44]. Laser cutting models are generally based on energy balance and the solution of a set of heat transfer equations to obtain a detailed temperature field evolution [36, 45, 46, 48 and 50]. Additional modeling endeavors have extended the level of analysis to incorporate other factors such as reactions between the assist gas and cutting front [16, 38 and 47], and dynamic effects of striation formation [30]. The modeling of laser cutting generally attempts to evaluate the cutting quality for given conditions [13 and 26] or to estimate the cutting capability for a given laser and material [8].

Previous mathematical models on laser beam cutting have involved fluid dynamics and heat transfer phenomena [12]. Arata et al. [52] discovered that the cutting speed was less than the speed of the moving molten layer, caused by the oxidation. Jae et al. [29] developed a 1-D with transient mathematical model for the prediction of striation formation in a reactive gas assisted laser cutting process. Reactive heat for oxygen cutting and the evaporation mechanism have been considered by Schuőcker [21] to calculate the dynamic phenomena responsible for the striation on the cut surface. The model deals with both the physical and chemical states at the cut front describing the characteristics of striation.

However, the existing models are not sufficient to fully demonstrate the dynamic behavior of laser cutting and the formation of periodic striations as shown in Fig. 1. Most of the models only relate the molten metal layer with constant cutting speed or constant laser power; no interactions are given for the time-dependent factors. In this paper, an analytical is developed to enable the analysis of the formation of molten layer, considering a number of process parameters. The enclosed area between melting front and cutting front is defined as the control volume (cv). Balance of mass, momentum and energy are integrated over the system boundaries in order to predict the melt film thickness, its displacement and velocity, laser absorption and cutting front temperature. The proprieties of the interfaces between the gas and liquid and liquid and solid are considered within the model.

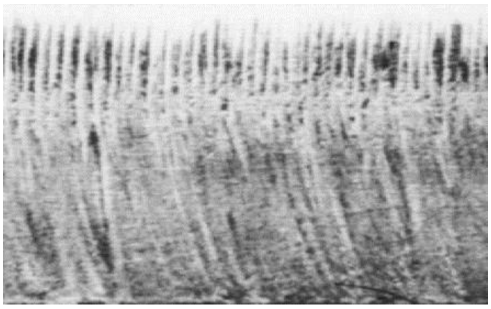

Figure 2.1: Typical cut edge mild steel showing the periodical striation

The process thickness for metals is mainly in the range of 1–6 mm, but the capability can extend beyond 25 mm (a cutting performance up to 120 mm sheet thickness has been achieved with a 2.5 kW CO_2 laser [51]. O'Neill and Steen [49] remark that "Process windows are empirically well defined. The need to develop mathematical models of the laser cutting process is still very real since quality demands placed on the process by industry are ever increasing as are the cost of experimental trials."

The scope of present study was to investigate the effects of laser processing on the quality and formation of phases in the cut surface. The cutting process was performed on commercially pure (CP) titanium (grade 2) and alloy Ti–6Al–4V (grade 5) sheets. A factorial arrangement regarding the several combinations of different processing factors will be built and the influence of these specific parameters, which are statistically significant for the process, will be evaluated by the analysis of variance statistical test.

The present study joins the current laser processing technology to relatively new material, titanium, aiming to optimize the process of pulsed laser cutting of thin sheets. As the processing aims the highest quality excellence, one must obey an optimized combination of parameters [35] as follows: power density; transversal laser beam mode; light polarization; process speed; material characteristics; geometry and diameter; work piece-focus distance; lens focal length; gas type, pressure, flux and purity; laser pulse energy and temporal length; wavelength; focal point distribution energy distribution among others.

The laser parameters described above lead to a complex interactive relations. Therefore the beginning of the study intends to present the most influent parameters during the cutting procedure and the possible interaction among them. An attempt to verify which parameters for the process gives the most adequate machining conditions as well as to establish the best parameters combination the analysis of variance will be conducted. Many experiments involve the analysis of effects of one or more factors in a system being studied. According to Montgomery [18], the method of varying one of the factors at a time and keep the others fixed is not adequate when there is a possibility of the influence of one factor over the other. In this case, the most appropriate is the use of factorial shapes where all the possible combinations of the factors will be investigated in a complete run of experiments.

Another interfering parameter on the quality of the cut is the gas supply. It is possible to observe cuts with all the possible combinations for three different pulse energy values and four different overlapping rate values of these pulses. The analysis of variance thorough the ANOVA statistical test concludes that these two parameters (laser pulse energy and overlapping rate) are important for the chosen factors (roughness and dross quantity). The analysis also shows that there is a significant interaction between these two parameters (*P*-values called the significance level). In general increasing the overlapping rate, i.e. closer pulses and lower speed values on the process, decreases the roughness and increases the dross quantity as well. Regarding the factors chosen for the experiment design, the energy per pulse and overlapping rate were highly influential to the process. The particular application must be evaluated for the best parameters choice since the enhancement of one of the cut characteristics (dross or roughness) leads probably to failure of the other characteristic. Obviously, this present study will explore some of the possible parameters which influence the laser machining. Only after the evaluation of all these several parameters it will be possible to have a clear scenario of the real importance of each one of them and the way to establish an "optimized" set that will enable to have a cut characterized by less irregular edges, low roughness and almost oxide-free under the laser optimum conditions for the titanium cut with the pulsed Nd:YAG laser.

An experiment is carried out and the theoretical predictions are compared with the experimental findings by B. S. Yilbas and A. Kar [1]. First and second law efficiencies of the cutting process are predicted, which may, then, be used to improve the process. It is found that the assisting jet velocity increases the first and second law efficiencies of the CO_2 laser cutting process. To relate the operating variables and characteristics of the laser to the parameters affecting the cut quality, many models have been developed over the years for the laser cutting process. Modeling provides considerable insight into the interaction mechanisms. Gas-assisted laser cutting process was previously modeled to investigate the forces exerted by an inert gas jet on the thin molten layer and, consequently, the equations of motion of the gas flow were solved. [14, 34, 39].

Often, two striation patterns are observable, with a regular pattern near the upper surface of the work piece. It has also been shown that pulsation in the absorbed laser power could cause both the thickness and temperature of the liquid layer to oscillate. [22] Consequently, a mathematical model determining the absorbed power intensity and liquid layer thickness developed on the upper surface of the work piece becomes necessary. In the light of the previous studies, [14, 31] the present study was to examine the power absorbed in the interface (gas–liquid) layer and liquid layer