IMPACT OF CO_2 LASER CUTTING PARAMETERS ON THE QUALITY OF CUT ON PMMA SHEET

HENG YEE WIEN

This thesis is submitted as partial fulfilment of the requirements for the award of the Bachelor of Mechanical Engineering with Manufacturing Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

DECEMBER, 2010

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

Signature
Name of Supervisor: LEE GIOK CHUI SMP. , KNM
Position:LECTURER
Date: 6 DECEMBER 2010

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature
Name: HENG YEE WIEN
ID Number:ME07024
Date: 6 DECEMBER 2010

ACKNOWLEDGEMENTS

This thesis is one of the requirements in obtaining the Bachelor of Mechanical Engineering with Manufacturing Engineering. I have been accompanied and supported by many people in this journey. It is a pleasant aspect that I have now the opportunity to express my gratitude to all of them.

First, a very special thank to my supervisor, Mr. Lee Giok Chui SMP. , KNM of his great patient and efforts in explaining things clearly. He always impressed me with his outstanding professional conduct and his strong conviction for science. I appreciate his consistent support from the first day I started this project. I am truly grateful for his progressive vision about my training in science and his tolerance of my mistakes.

By the way, I would like to thank Mr Mak from Leong Art Advertisement for giving out his help in completing this project. I would also like to thank all members of the staff of the Mechanical Engineering Department, UMP, who helped me in many ways and made my stay at UMP pleasant and unforgettable.

Lastly, I would like to thank to all my fellow friends for giving me supports and advice to me to keep looking forward when I am facing a lot of problems and boundaries in completing my Final Year Project.

ABSTRACT

The quality of laser cut is of the utmost importance in laser cutting process. All cutting parameters might have significant influence on the resulting quality of work. In general, cutting parameters are adjusted and tuned to provide the quality of cut desired. But this consumes exhaustive amounts of time and effort. Therefore, it is important to investigate the impact of cutting parameters on quality of cut. The aim of this study is to relate the CO_2 laser cutting parameters namely laser power, cutting speed and tip distance to the quality of cut of PMMA sheet. The quality parameters considered include surface roughness, kerf width and heat affected zone. The effects of each cutting parameters on quality of cut was establish and the interactions between the cutting parameters were investigated.Design of experiment was used by implementing Box-Behnken design to identify the main effects and interactions of the parameters. Perthometer S2 and microscope MarVision MM320 are carried out to examine the surface roughness, kerf width and heat affected zone. The yields of responses are then analyzed by using STATISTICA software. The statistical analysis reveals that the surface roughness and kerf width are significantly affected by tip distance followed by cutting speed. Laser powers do affect the surface roughness and kerf width but its effects are negligible when compared to cutting speed and tip distance. It is also found that all three cutting parameters have significant effects on the variation of heat affected zone. A significant interaction exists between cutting speed and tip distance as shown in statistical analysis.

ABSTRAK

Kualiti pemotongan adalah sangat penting dalam proses pemotongan laser. Semua parameter proses berkemungkinan mempunyai pengaruh yang penting terhadap kualiti hasilan. Secara umumnya, parameter proses diselaras dan ditala untuk memberikan kualiti potongan yang dikehendaki. Tetapi ini mengambil masa dan usaha yang banyak. Oleh itu, ia adalah penting untuk menyiasat kesan parameter proses terhadap kualiti pemotongan. Tujuan utama kajian ini adalah untuk mengaitkan parameter proses pemotongan laser gas CO_2 iaitu kuasa laser, kelajuan pemotongan dan jarak penghujung terhadap kualiti pemotongan lembar PMMA. Jarak penghujung ialah jarak antara nosel dengan permukaan benda kerja. Parameter kualiti yang dikaji meliputi kekasaran permukaan, kelebaran kerf , dan zon terpengaruh panas. Kesan-kesan parameter proses pada kualiti dan interaksi antara parameter proses telah dikaji. Eksperimen Yang Terancang (DOE) dan menggunakan cara Box-Behken untuk mengenalpasti kesan-kesan utama dan interaksi parameter. Perthometer S2 dan mikroskop MarVision MM320 digunakan untuk mengukur kekasaran permukaan, kelebaran kerf dan zon terpengaruh panas. Keputusan eksperimen dianalisis dengan meggunakan perisian STATISTICA. Analisis statistik menunjukkan bahawa kekasaran permukaan dan kelebaran kerf adalah terjejas dengan nyata sekali oleh parameter jarak penghujung dan diikuti oleh kelajuan pemotongan. Kuasa laser menjejaskan kekasaran permukaan dan kelebaran kerf juga. Tetapi kesannya adalah sedikit dan boleh diabaikan apabila berbanding dengan parameter kelajuan pemotongan dan jarak penghujung. Selain itu, ia juga didapati bahawa ketiga-tiga parameter mempunyai kesan yang signifikan terhadap zon terpengaruh panas. Analisis statistik juga menunjukkan kewujudan interaksi yang signifikan antara kelajuan pemotongan dan jarak penghujung.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

^{o}C	Degree Celsius
Hz	Hertz
IPS	Inches per second
%	Percent
Psi	Pound per square inch

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
CO_2	Carbon dioxide
HAZ	Heat affected zone
Nd:YAG	Yttrium-aluminum-garnet
PMMA	Polymethyl Methacrylate
Ra	Arithmetic mean value

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

CO_2 laser machine has been used in industry for many applications such as laser cutting, laser engraver and laser marking. Laser cutting process is one of the famous applications of laser machine in industry. Laser beam usually used to cut small and precise products for assembly parts. The finished product of laser cutting process does not need any further finishing process. However, poor quality of cut has been rise as critical issues in industry due to the improper setting of cutting parameters. In order to solve this problem, a research study on the impact of cutting parameters on quality of cut was carried out. In this research, the main objective will focus on the impact of the cutting parameters of a specify machine on the quality of cut on Polymethyl Methacrylate (PMMA) sheet.

1.2 PROJECT BACKGROUND

The laser, an acronym that stands for Light Amplification by Stimulated Emission of Radiation, has advanced over time and has many applications today.Laser cutting is a technology that uses a laser beam to cut precise patterns in most all types of materials such as metal, plastic and paper. With its high level of accuracy and flexibility, laser cutting are used in a large variety of industrial application to replace conventional machining processes such as plasma and oxy-fuel cutting.

There are two types of lasers used for cutting which is gaseous CO_2 laser and the solid state Nd:YAG(yttrium-aluminum-garnet) laser. CO_2 laser is one of the most important lasers in laser machining of materials. This is a molecular gas laser consisting

of CO_2 gas as its active medium (Dahotre and Harimkar, 2008). CO_2 lasers work by pumping the atoms of gaseous mixture into an excited state within the laser's chamber. The laser beam is then focused by a lens on the surface of the material being cut. The laser beam either melts, burns or vaporized the material in a localized area. Correct use of cutting parameter can produce good square cuts with high quality finish.

This project will focus on the impact of CO_2 cutting parameter on the quality of cut on PMMA sheet. The cutting parameter is the main key in determined the quality of cuts. Different set of parameter may obtain different quality of cuts. There is several application issues involve in laser cutting technology which is cut quality, thick section cutting, and use of laser cuttable steels. In laser cutting process, the end product quality is the determining factor for the successful machining operation. All cutting parameters might have significant influence on the resulting quality of work. The interactions between the cutting parameters may exist and it might affect the quality of work in significant ways. The impacts of cutting parameters are important and yet to investigate.

1.3 SIGNIFICANCE OF THE STUDY

Nowadays, quality is an important element in business and industries. In order to fulfil the requirements of customer, the product that provided by a company must be in good quality to exceed the expectation of the customers. For instance, if high precision cut is the main concern of the customer, the setting of cutting parameter must have optimum effects on the kerf width. The present study is aimed to investigate the effect of each parameter on the quality of cut. The desired quality of cut can be produced in shortest time once the impact of each parameter is known. The requirement of quality may differ for different applications. It depends on the customer quality requirement. A high quality of cut does not always necessary. Hence, it is important to study the impact of cutting parameters on quality of cut.

Besides, Polymethyl Methacrylate (PMMA) is one of the common acrylic plastic which required careful handling because it is not easily recycled. It is considered a group 7 plastic among recycled plastics and is not collected for recycling in most communities. Wasted PMMA sheet may cause pollution to environment. Once the

relationship between cutting parameters and quality characteristics are investigated, the desired quality of cut can be produced in a single pass. Thus, it reduces the waste of PMMA. At the same time though, it reduces the cost of production.

1.4 PROBLEM STATEMENT

Quality of cut has been a critical issue in laser cutting process. For plastic cutting such as polycarbonates and PVC, the edges will always be brown or yellow, and it produces hydrochloric acid during the cutting, which will eat up everything inside the laser and in the exhaust system. Currently, there are some problems with the laser cutting process which require immediate attention. Process parameters are adjusted and tuned to provide the quality of cut desired. This consumes exhaustive amounts of time and effort, and still the optimal cutting conditions may not be found. This issue of optimized parameter selection is currently being addressed.

When using incorrect parameter, it will result in a different quality of cut. Thus, the end product may need to go through finishing operation. This additional process adds to the cost of production. The relationships between the quality of cut and cutting parameters are important and yet to investigate.

1.5 PROJECT OBJECTIVE

The main objectives of this project are to study the impact of CO_2 laser cutting parameters on:

i. Surface roughness of cutting edge
ii. Kerf width
iii. Heat affected zone

1.6 PROJECT SCOPE

In order to achieve the objectives of this project, the scopes are list as below:

i. The process parameters implemented in the study are laser power, cutting speed and tip distance.

ii. Epilog Legend 24 EX (60 watt) is used to perform laser cutting process.
iii. Compressed air is used as assist gas and air pressure is fixed at 20psi.
iv. The frequency of laser beam is fixed at 2500 Hertz.
v. PMMA sheet with 2.0mm in thickness is used in the experiment.
vi. Statistica 7.3 software is used to analyse the experimental results.

1.7 SUMMARY

At the end of this research, the impact of cutting parameters on the quality of cut could be identified through.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Laser cutting processes have been widely used in most manufacturing industries. In comparison to other cutting processes, it has several advantages. It belongs to the most rapid cutting processes, the forces acting on a product during cutting being negligible, therefore, no particular clamping of work piece is required in cutting even the thinnest of materials. There are three main cutting methods using laser cutting process which is laser fusion cutting (inert gas cutting), laser vaporization cutting and laser oxygen cutting. Different method is applied when cutting different materials. For example, flame cutting is particularly well suited to cutting mild steel. As the material melts, most of it oxidizes. It is then blown out of the kerf along with the ferric oxides. Obtaining good laser processing results requires careful preparation of the material and machine processing parameters. Each processing parameters have different impact on the quality of cut. Impact of each processing parameters such as laser power, cutting speed, gas pressure and focus position required extensively study to improve the quality of cut. The quality of cut can be determined from the surface quality and edge quality. Each of the quality was measured by using standard process.

2.2 CO_2 LASER MACHINE

Laser cutting machines are distinct from traditional mechanical cutters. The laser cutter never makes physical contact with material and there is less opportunity for the material to become contaminated. Laser cutting machines also cut material with higher precision than that of mechanical means. The most common type of laser cutter available in industry today is the CO_2 laser.

The three processes required to produce the high-energy laser beam are population inversion, stimulated emission, and amplification (Dahotre and Harimkar, 2008). Population inversion is a necessary condition for stimulated emission. According to the Boltzmann law, the higher energy states are the least populated and the population of electrons in the higher energy states decreases exponentially with energy (Dahotre and Harimkar, 2008). Population inversion corresponds to a non-equilibrium distribution of electrons such that the higher energy states have a larger number of electrons than the lower energy states. The process of achieving the population inversion by exciting the electrons to the higher energy states is referred to as pumping. There are two types of pumping system which is optical pumping and electrical pumping. Optical pumping is used for solid-state lasers like ruby and Nd:YAG (yttrium-aluminum-garnet). Electrical pumping is used to serve as pump source in gas laser. It pumps a high-voltage electric current directly through the mixture of active gas medium. If CO_2 gas is used as a medium, thus it was known as CO_2 laser machine.

Stimulated emission results when incoming photon of frequency *v* interacts with the excited atom of active laser medium. The incoming photon triggers the emission of radiation by bringing the atom to the lower energy state (Dahotre and Harimkar, 2008). The resulting radiations have the same frequency, direction of travel and phase as that of the incoming photon. Amplification of the laser light is accomplished in a resonant cavity consisting of a set of well-aligned highly reflecting mirrors at the ends, perpendicular to the cavity axis (Dahotre and Harimkar, 2008). Usually, one of the mirrors is fully reflective with reflectivity close to 100%, whereas the other mirror has some transmission to allow the laser output to emerge (Dahotre and Harimkar, 2008). Once the lasing material is stimulated, a beam is reflected and bounced off a partial mirror. It is allowed to collect strength and sufficient energy, before escaping as a jet of monochromatic coherent light. As the laser cuts through material, some materials will have a little bit of flame up. To reduce this problem, the laser machine includes the air assist. Air assist is used to remove heat and combustible gases from the cutting surface. By directing a constant stream of compressed air across the cutting surface, the possibility of flaming, scorching and charring is reduced when cutting.

In this study, a CO_2 laser machine which model is Legend 24 EX from Epilog Company was used to perform the cutting process. The air assist assembly is connected to a standard compressed air supply with maximum pressure of 30 psi. In this research, we have fixed the gas pressure at 20psi.This machine can be used to cuts wood, acrylic, glass, anodized aluminum, leather, mat board and plastic. However, it cannot used to cut any material containing Polyvinyl Chloride (PVC) or vinyl. This is because a corrosive agent will be produced and it will destroy the machine. The recommendations requirement for computer which work with this machine is as stated in Table 2.1. CorelDraw is the software which used to setup the artwork of laser cutting. Legend 24 EX was installed with CorelDraw 10. Table 2.2 shows the specification of the Legend 24 EX. Servo motor is use to control the motion of the machine and thus it has maximum cutting speed up to 80 IPS (Inches per second). The maximum output power of the CO_2 laser machine is 60 watt. Besides that, the CO_2 laser machines comply with CDRH class IIIa. This safety class means that the features of the laser machine met the required safety features which are laser radiation emission indicator, beam attenuator, warning affixed and instruction manual. Figure 2.1 shows the full size of Epilog Legend 24 EX CO_2 laser machine. Figure 2.2 shows the table size of the Legend 24 EX CO_2 laser machine.

Table 2.1: Computer Recommendations

Features	**Requirements**
Operating system	Windows 2000 or XP (any version)
Installed Memory	512 MB RAM
Processor	2.0 GHz or faster processor
Graphic	10/100 Network Interface Card
Disk space	20-30 GB Hard Drive (Minimum)
Drawing software	Corel 10, 11, or 12

Source: Epilog Machine Manual

Table 2.2: Specifications of Epilog Legend 24EX

Features	**Specifications**
Maximum Material Thickness	228 mm (Non-metallic Sheet)
Size/Weight	965mm wide ×826mm deep ×1016 mm high /160kg
Operating Modes	Optimized raster engraving, vector cutting, or combined raster/vector mode.
Laser Source	Air-cooled CO_2 laser tubes are fully modular, permanently aligned, and field replaceable/upgradeable. 2'' focus length (51mm).
Motion Control	High speed, continuous loop, servomotors (80 IPS) using linear encoding technology for precise positioning
Speed/Power Control	Computer or machine controlled Speed and Power in 1% increments to 100%. Vector colour mapping links Speed and Power setting to any RGB colour.
Electrical Requirements .	Auto-switching power supply accommodates 110 to 240 volt, 50 or 60 Hz, single phase, 15 amp AC
Standard Features	Red Dot Pointer, Air Assist (pump optional), Auto Focus, 2" focus lens, relocatable home, flash upgrade electronics
Safety	CDRH class IIIa

Source: Epilog Machine Manual

Figure 2.1: Epilog Legend 24 EX

Source: Epilog Machine Manual

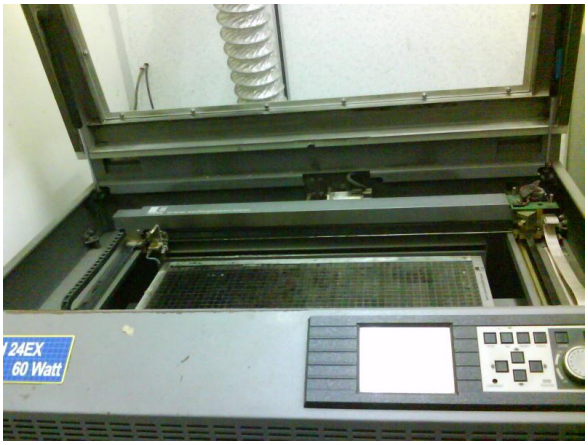

Figure 2.2: Table size of Epilog Legend 24EX

2.3 LASER CUTTING PROCESS

Laser (Light Amplification by Stimulated Emission of Radiation) emits a special type of light. The light emitted by a laser is monochromatic and coherent. The properties of laser light are what make it possible to bundle the light into a beam and focus the beam down to a tiny point for material processing applications requiring a high degree of precision. CO_2 lasers emit infrared laser radiation with a wavelength of 10.6 um and posses overall efficiencies of approximately 10 to 13 % (Wandera, 2006).