EXPERIMENTAL STUDY OF THE LASER BEAM CUTTING ON ACRYLIC SHEET

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Thesis submitted in fulfilment of the requirements for the award of the degree of Bachelor of Mechanical Engineering

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NOVEMBER 2009
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.

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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.

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Dedicated to my beloved father and mother
ACKNOWLEDGEMENT

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ABSTRACT

In this modern era, especially in advanced engineering materials, it was realized to develop some of non-conventional machining methods known as advanced machining process (AMPs). Laser Beam Machining (LBM) is one of the AMPs that are being used nowadays for shaping almost whole range of engineering materials. LBM are widely used for cutting, drilling, marking, welding, sintering, and heat treatment but for this project, this will focus only on cutting. This project is about experimental study of laser beam cutting on acrylic sheet. Cutting experiment will be done on acrylic sheet with thickness of 3mm using PCNC Laser Cutting Machine. The experiment held under some parameters such as cutting angle, cutting speed, laser power, nozzle gap, and air pressure. Response Surface Method (RSM) used to design the experiment which result 40 number of experiment with different values of parameters. The objective of this project is to find the parameter that produced best cutting quality of acrylic sheet. Cutting quality judged by measuring surface roughness of the specimen by using surface roughness tester, MahrSurf XR 20 with Perthometer S2. Two profile parameters that considered in order finding best cutting quality were Roughness Average, Ra and Maximum Roughness Depth, Rmax. From the experiment, the result analyzed and it was found the best cutting quality and parameters that produced that cut. Every parameter has their relationship between each other which affect the quality of cutting. In order to produce better surface, there are some recommendation that can be consider for future research.
ABSTRAK

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LIST OF SYMBOLS

$CO_2$ : Carbon Dioxide

$Ra$ : Average surface roughness

$Rz$ : Average maximum height

$RzJ$ : Japanese standard for average maximum height

$Rq$ : Root mean square roughness

$R_{max}$ : Maximum roughness depth

LIST OF ABBREVIATIONS

LBC : Laser beam cutting

CNC : Computer numerical control

PCNC : Personal computer numerical control

HAZ : Heat affected zone

DOE : Design of experiment

RSM : Response surface methodology
CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

In this modern era, especially in advanced engineering materials, it was
realize to develop some of non-convectional machining methods known as advanced
machining process (AMPs). Laser Beam Machining (LBM) is one of the AMPs that
being used nowadays for shaping almost whole range of engineering materials. LBM
are widely used for cutting, drilling, marking, welding, sintering, and heat treatment
but for this project, this will focus only on cutting.

This project is about Experimental Study of the Laser Beam Cutting on Acrylic
Sheet. The term laser is a short form of Light Amplification Stimulation Emission of
Radiation (LASER) [1] and the Laser Beam Cutting (LBC) is a method of cutting
metal utilizing a high intensity laser for melting and vaporizing material and related to
laser beam machining [2].

A medium, either gaseous or solid, is excited to emit a monochromatic (single
wavelength) coherent source of light. This light can be focused to a point source, called
spot size, resulting in very high power, densities, capable of vaporizing various
materials. By controlling the power density, through the laser power and spot size, and
with the assistance of gases, laser cutting and welding can be achieved. The two most
common types of industrial lasers are CO\textsubscript{2} and Nd:YAG. CO\textsubscript{2} use a gaseous medium
for the lasing action while the Nd:YAG use a crystalline material. The CO\textsubscript{2} lasers are
commercially available in powers up to 40 kW and Nd:YAG systems to 5 kW. The
Nd:YAG were commonly used because of its high intensity, low mean beam power,
good focusing characteristics, and narrow heat affected zone (HAZ). Laser beam
cutting (LBC) also can be successfully used for the cutting of conductive and nonconductive difficult-to-cut advanced engineering materials such as reflective metals, plastics, rubbers, ceramics and composites.

Apart from cutting difficult-to-cut materials, LBC is most widely used in industries to achieve complex shapes/profiles with close tolerances for cutting of steel sheets [3].

![Schematic of Laser Beam Cutting (LBC)](image)

**Figure 1.1:** Schematic of Laser Beam Cutting (LBC)

Laser beam cutting (LBC) is achieved by the radiation emitted by a focused beam of coherent light with the assistance of a high pressure gas. An assist gas is used to remove the melted and volatilized materials from the beam path. Both metallic and non-metallic materials can be cut by the laser beam process. The output beam is often pulsed to very high peak powers in the cutting process. Pulsing generally increases the travel speed of the cutting operation [4].

It is a thermal energy based non-conventional cutting method in which sheet material is cut mainly due to melting and vaporization [5]. The quality of cut solely depends on the setting of process parameters such as laser power, type and pressure of
assist gas, sheet material thickness and its composition, cutting speed, and mode of operation (continuous wave or pulsed mode).

Advantages of LBC include:

- complex figures can easily be cut by incorporating CNC motion equipment
- high cutting speeds
- low distortion
- low dross
- minimal heat affected zones
- very high edge cut quality
- very narrow kerf width

1.2 PROBLEM STATEMENT

In the industry sector, they are various ways to cut materials. One of them is using laser machine that is Laser Beam Cutting. This project is to help the industry to cut the various type of material that used in the industry by using laser machine. By using this method, they can cut any shape that they want easily where it is hard to use another machine or method to cut it. So practically, this method can help the industry in cutting their materials.

There were some problems that need to be tackled such as using the Microsoft Excel Software to analysis data or to find pattern in data. Besides that, the type of materials that need to used in this project also has to determine and have to produce the finest and the most quality of cut. There are some parameters that have to consider such as laser power, type and pressure of assist gas, cutting materials thickness and its composition, cutting speed, and mode of operation (continuous or pulsed) on process performance. All of these parameters have to be determined before doing an experimental study of laser beam cutting.
1.3 OBJECTIVE PROJECT

The aim of this project is generally to:

- To study of the Laser Beam Cutting (LBC) on Acrylic Sheet.
- To find the best parameters that can produce the finest and most quality of cutting quality on Acrylic sheet by analysis using Microsoft Excel.

1.4 PROJECT SCOPE

This project will focus mainly on one of the Laser Beam Machining function that is Laser Beam Cutting. In order to achieve the objective notified earlier, the following scopes have been recognized:

1. The machine that will used is PCNC Laser Cutting Machine (30 Watt)

2. Cutting parameters will be determined before doing the experiment and the quality of cut determined by doing surface roughness test.

3. The result will be analyzed by using Microsoft Excel and from that we can see the best quality of cutting.

4. Material that used is Acrylic sheet with thickness of 3 mm.

This project will be doing in Faculty of Mechanical Engineering (FKM) Laboratory in University Malaysia Pahang (UMP).
CHAPTER 2

LITERATURE REVIEW

2.1 LASER BEAM CUTTING

Laser light differs from ordinary light because it has the photons of same frequency, wavelength and phase. Thus, unlike ordinary light laser beams are high directional, have high power density and better focusing characteristics. These unique characteristics of laser beam are useful in processing of materials. The laser beams are widely used for machining and other manufacturing processes such as, cutting, drilling, micromachining, marking, welding, sintering, and heat treatment.

Laser beam cutting (LBC) can be successfully used for the cutting of conductive and non conductive difficult-to-cut advanced engineering materials such as reflective metals, plastics, rubbers, ceramics and composites. Apart from cutting difficult-to-cut materials, LBC is most widely used in industries to achieve complex shapes/profiles with close tolerances for cutting of steel sheets. In laser beam cutting (LBC) process, the thermal energy of laser beam is used for melting and vaporizing the sheet metal. The molten material is removed by using suitable assist gas at high pressure (figure 2.1). The most widely used lasers for sheet cutting are continuous wave (CW) CO2 and pulsed Nd:YAG [6]. Pulsed Nd:YAG laser cutting becomes an excellent cutting process because of high laser beam intensity, low mean beam power, good focusing characteristics, and narrow heat affected zone (HAZ) [7]. There has been growing interest in recent years in the use of pulsed Nd:YAG lasers for precision cutting of thin sheet metals and for applications that demand narrow kerf widths and intricate cut profiles. Due to its shorter wavelength (1.06_m) in comparison to CO2 (10.6_m), it is reflected to a lesser extent by
metallic surfaces and this high absorptivity of the Nd:YAG laser enables cutting of even highly reflective materials with relatively less power [8].

Figure 2.1: Schematic of Nd:YAG laser beam cutting system.

LBC has always been a major research area for getting the exceptionally good quality of cut. The quality of cut solely depends on the setting of process parameters such as laser power, type and pressure of assist gas, sheet material thickness and its composition, cutting speed, and mode of operation (continuous wave or pulsed mode). A lot of experimental investigation has been undertaken with the aim of analyzing the effect of process parameters on cut geometry, and cut surface quality. In most of the experimental investigations of the LBC process, researchers have varied one factor at a time to analyze the effect of input process parameters on output quality characteristics or responses. But this technique requires a large number of experimental runs because only one factor is varied in each run, keeping all other factors constant. Also, in this technique, the interaction effects among various input process parameters are not considered. To overcome these problems, some researchers have incorporated design of experiments
methodologies such as the response surface methodology (RSM) and Taguchi methodology (TM) during experimental study of LBC process [9].

2.2 PARAMETERS

The experiments have been conducted by different researchers with the factors or process variables that are considered to be the most important without using any scientific method of experimental design. The results obtained are used to investigate the effect of each factor as well as the influencing mechanism on the observed quality characteristic.

Experiments on Nd:YAG laser beam cutting of metals and alloys have been reported by various authors. Grevey and Desplats (1994) have compared the cutting performance of continuous wave (CW) and pulsed Nd:YAG laser beam for cutting bare and coated metal plates (0.8–2.0mm thick) of car frame using oxygen assist gas. They have found that the cutting speed obtained was more in case of CW laser, bare metal and thinner plate. The highest cutting speed recorded was 5m/min at an optimum oxygen pressure of 3 bar [10].

Tahmouch et al. (1997) have performed the experimental study for cutting stainless steel sheets (up to 2 cm thick) from a long distance (1 m) without using any assist gas in pulsed mode taking pulse frequency (100–200 Hz), peak power (2–5 kW) and cutting velocity (0.05–0.5 m/min) as process variables. Their study revealed that less power density is required to cut without assist gas in comparison to classical cutting and sheets up to 2 cm thick can be cut successfully at a long distance. They have also found that low pulse frequencies and high peak powers were favorable for higher cutting speeds [11].

Kaebernick et al. (1999) have performed the experiments on mild steel and stainless steel sheets (0.5 and 0.9mm thick) in pulsed mode using oxygen assist gas at constant pressure of 700 kPa. Variation of kerf width was recorded by varying cutting speed (600–800 m/min) and pulse width (0.2–0.9 ms) keeping pulse energy (0.35 for 0.5mm sheet and 0.7 J for 0.9mm sheet) and frequency (170 and 100 Hz, respectively, for 0.5 and 0.9mm sheets) at constant values for each specimen. They have found that the kerf
width increases slightly with increase in cutting speed up to a critical value then starts decreasing. This critical value depends on pulse width and increases with increasing pulse width [12].

Han et al. (2005) have performed the experiment in CW mode on H13 tool steel and stainless steel 304 substrates at different power levels (300–1000W) and processing speeds (6.3–17 m/s). Melt pool depth and width were found to be increased with increasing power while processing speed shows no significant effect. The maximum temperature was recorded at the middle of the melt pool geometry [13]. Effect of mechanical cutting and laser cutting on magnetic properties of nonoriented electrical steel sheets (300mm×100mm×0.5mm) have been experimentally investigated using pulsed Nd:YAG laser (Loisos and Moses, 2005). It was found that cutting at slow speed using special type of laser beam system of maximum average power 100W there was no change in magnetic properties while in mechanical cutting the magnetic flux density extends up to 5–6mm from each side of the cutting edge.

From the experiments that have been prove by the others researcher, it can be said all the parameters affected the LBC process. Cutting speed has to be more if the cutting mode is continuous wave. And if there was no assist gas use, less power density is required to cut the material from a long distance. For high cutting speed, it is suggested to use low pulsed frequencies and high peak power to obtain the good quality of cutting. But, increasing the cutting speed will increase the kerf width up to the critical value and then decrease. The pulse width was influence this critical value. It was also observed that smaller kerf width and smoother surface is obtained by increasing cutting speed and frequency while decreasing the power and gas pressure. The parameters that have to be considered are:

2.2.1 Laser Power

Laser power depends on the type of laser used. For this project, the laser that we used is continuous wave (CW) CO₂ type that have power maximum to 30 Watts. But the power only can be used until 95% to the maximum power. Meaning that, the maximum power that we can use is about ±28.5 Watts. So far, the machine that had in the FKM lab
was only cut the PVC. It never been tested with other materials that harder or stronger materials such as aluminium. Then the suggested laser power is 25.5 Watt, 26.5 Watt, 27.5 Watt, and 28.5 Watt. Then we can determine what laser power will produce the best cutting quality.

2.2.2 Cutting Speed

Cutting speed for PCNC Laser Cutting Machine can be various depends on what we want to do. The speed is measured in pulse. For cutting, the best cutting speed for cutting PVC is 700 pulsed. But for materials aluminum and phosphorus (bone) we have to determine the best cutting speed. The cutting speed that will be used is 900, 1000, 1100, and 1200 pulse. Then the best cutting quality can be determined by which cutting speed.

2.2.3 Type and Pressure of Assist Gas

PCNC Laser Cutting Machine used the air as the assist gas. This assist gas is to help to move the molten materials at the surface of the materials. The gas also can suck the smell of the gas. The air pressure will be up to maximum 10 bars.

2.2.4 Cutting Material Thickness and its composition

This project will used acrylic as material that need to cut. Acrylic is a one of the types of PVC. Since this machine only cut PVC, the maximum PVC that successfully been cut is 15mm. And for this project, the thickness of the acrylic used Is only 3mm. so if should be no problem for PCNC Laser Cutting Machine with maximum power up to 30W to cut it.

2.2.5 Mode of Operation

Mode of operation for this machine is pulsed mode. This is mode for cutting materials. But the laser will operate in continuous wave (CW) mode.

2.2.6 Cutting Angle
The cutting angle that will be used in this experiment is 0°, 2°, 4°, and 6°. Then we have to determine what angle is the best angle that can be used to cut our materials.

### 2.2.7 Nozzle gap

One of the parameters that will influence the cutting quality is the gap between laser nozzle and the materials. Each distance will cause different effect on the materials that we are cutting. So in this experiment, the suggested gap was 1mm, 2.5mm, 4.5mm, and 6.0mm.

**List of parameters:**

- Laser Power = 25.5 Watt, 26.5 Watt, 27.5 Watt and 28.5 Watt
- Cutting Speed = 900, 1000, 1100, 1200 pulse
- Type and pressure of assist gas = Air (0, 1, 2, 3 bar)
- Material thickness = Acrylic (3 mm)
- Mode of Operation = Pulsed
- Cutting Angle = 0°, 2°, 4°, 6°
- Nozzle gap = 1mm, 2.5 mm, 4.5mm, 6.0mm

### 2.3 CUTTING QUALITY

Also based on the experiment that have been done by the previous researcher, It was found that the laser cutting quality (dross adherence, kerf width, surface roughness and HAZ) depends mainly on the cutting speed, cutting mode, laser power, pulse frequency and focus position. Due to converging–diverging shape of laser beam profile (Fig. 3) the kerf taper always exist during LBC. Various researchers have experimentally studied the laser cut qualities such as kerf width and kerf taper in order to analyse the effect of various process parameters on these quality characteristics. Chen (1999), during his experimental investigation, found that kerf width increases with increasing laser power and decreasing the cutting speed during CO2 laser cutting of 3 mm-thick mild steel sheet [14]. He also observed that oxygen or air gives wider kerf while use of inert gas gives the narrow kerf.
Ghany and Newishy (2005) have observed the same variation of kerf width with cutting speed, laser power, and type of gas and pressure as above during experimental study of Nd:YAG laser cutting of 1.2 mm-thick austenitic stainless steel sheet. They have also found that on increasing pulse frequency the kerf width decreases [15].

The three main quality characteristics of laser cut kerf that decides the kerf geometry are kerf taper (Kt), kerf deviation (Kd) along the length, and kerf width (Kw). The schematic of laser cut kerf is shown in Fig. 4. The kerf qualities studied so far does not include the kerf unevenness or kerf deviation along the length of cut which is an important quality characteristic for achieving the stringent design requirements. TM- or RSM-based studies applied for LBC process were aimed to optimize a single quality characteristic at a time. But it is always desired to optimize the multiple quality characteristics of the product or process at the same time. Also, researchers have not tried for optimizing the kerf qualities during pulsed laser cutting of aluminium/aluminium-alloy sheets, which are highly reflective and heat sensitive (thermally conductive) material and pose difficulty during LBC. Authors have found only one paper concerned with laser cutting of aluminium alloy sheet by Araujo et al. (2003) who have experimentally studied the microstructure in HAZ during LBC of 2024 aluminium alloy sheet by CW CO2 laser beam without using any of DOE techniques [16].

![Figure 2.2: schematic of typical beam profile](image-url)