



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**OPTIMIZATION OF MACHINING PARAMETERS IN LASER
CUTTING**

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

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DECLARATION

I hereby, declared this report entitled optimization of machining parameters in laser cutting is the results of my own research except as cited in references.

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APPROVAL

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

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ABSTRACT

This report presents a study of optimization on machine parameters of CO₂ laser cutting. Laser output power, feed rate and assisting gas pressure were selected as the major factors that will be analysed and optimized in this study. The kerf width and surface roughness were the process responses that obtained after the experiment trials which require checking by using optical comparator and surface roughness tester respectively. The material that selected in this study was mild steel 1020 that contain 0.18-0.23% carbon. The range for the laser power, feed rate and assisting gas pressure selected were 2000-2500Watts, 1200-1700mm/s and 4.5-5.5Bar respectively. The Helius 2513 CO₂ laser beam cutting machine was used to conduct the experiment. Design of experiment (DOE) was used to plan the whole research. Response surface methodology (RSM) was the main technique that applies in this study to design the experiment order and array. Laser output power and feed rate had a major effect on the kerf width, while assisting gas pressure played a minor role. Decreasing power, increasing feed rate and increasing the gas pressure generally led to a decrease in kerfs width. At high and low power level, increasing feed rate create the similar decrease in kerf width. Feed rate had the most significant effect on surface roughness. Laser power had the second most significant effect on surface roughness. Increasing feed rate and reducing laser power generally lead to reducing of surface roughness. Interaction between feed rate and assisting gas pressure had the third most significant effect to the surface roughness. Increasing of both gas pressure and feed rate and reduce laser power can lead to reducing of surface roughness. At low feed rate level, the assisting gas pressure is directly proportional to surface roughness. At high feed rate level, the assisting gas pressure is inversely proportional to surface roughness. As the suggestion, the experiment trails should be carried out at least two times to reduce the potential interruption that may occur.

ABSTRAK

Laporan ini mempersembahkan kajian terhadap optimisasi pada parameter-parameter untuk mesin pemotongan laser CO₂. Kuasa keluaran laser, “feed rate” dan tekanan gas dipilih sebagai faktor utama yang akan dianalisis dan dioptimumkan dalam kajian. Lebar pemotongan dan kekasaran permukaan pula adalah reaksi proses yang akan didapatkan melalui peralatan “optical comparator” dan “surface roughness tester”. Bahan yang memilih dalam kajian ini adalah keluli lembut AISI 1020 yang mengandungi 0.18-0.23%. Julat untuk kuasa laser, “feed rate” dan tekanan gas terpilih adalah 2000-2500Watts, 1200 1700mm/min dan 4.5-5.5Bar masing-masing. Heliuss 2513 adalah mesin pemotongan laser CO₂ yang digunakan dalam kajian ini. Response Surface Methodology (RSM) adalah teknik utama yang digunakan dalam kajian mereka bentuk eksperimen. Kuasa keluaran laser dan “feed rate” mempunyai kesan utama pada kelebaran “kerfs”, manakala membantu tekanan gas memainkan peranan kecil. Pengurangan kuasa laser, pertambahan “feed rate” dan pertambahan tekanan gas dapat mengurangkan kelebaran “kerfs” secara berkesan. Pada aras kuasa laser tinggi dan rendah, pertambahan “feed rate” mewujudkan pengurangan yang sama terhadap kelebaran kerf. “Feed rate” mempunyai kesan yang terketara terhadap kekasaran permukaan. Kuasa laser mempunyai kesan yang kedua terketara terhadap kekasaran permukaan. “Feed rate” bertambah dan mengurangkan laser kuasa dapat mengurangkan kekasaran permukaan. Interaksi antara “feed rate” dan tekanan gas mempunyai kesan yang ketiga ketara terhadap kekasaran permukaan. Pertambahan tekanan gas dan “feed rate” serta mengurangkan laser kuasa boleh mengurangkan kekasaran permukaan. Pada tahap “feed rate” rendah, tekanan gas adalah berkadaran terus terhadap kekasaran permukaan. Pada tahap “feed rate” tinggi, tekanan gas adalah berkadar songsang terhadap kekasaran permukaan. Sebagai cadangan, eksperimen dijalankan sekurang-kurangnya dua kali untuk mengurangkan potensi gangguan yang mungkin berlaku.

DEDICATION

For my beloved parents and family.

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LIST OF ABBREVIATIONS

CCD	-	Central composite design
Cm	-	Centimeter
CNC	-	Computer numerical control
CO ₂	-	Carbon dioxide
DOE	-	Design of experiment
EDM	-	Electrical Discharge Machining
FD	-	Factorial design
FeO	-	Iron Oxide
HAZ	-	Heat affected zone
In	-	Inch
Kg	-	Kilogram
LBM	-	Laser beam machining
LBC	-	Laser beam cutting
LCD	-	Liquid crystal display
mg	-	Milligram
min	-	Minutes
mm	-	Millimeter
MRR	-	Material removal rate
ms	-	Millisecond
N ₂	-	Nitrogen
O ₂	-	Oxygen
PCA	-	Principal component analysis
PCM	-	Photochemical Machining
PSM	-	Projek sarjana muda
RSM	-	Response surface methodology
SEM	-	Scanning electron microscopy
SOD	-	Stand off distance
W	-	Watt

CHAPTER 1

INTRODUCTION

This chapter shows the introduction of the laser beam machining, background of problem, statement of problem, objective and scope of the study.

1.1 Introduction

Laser beam machining (LBM) is one of the most widely used thermal energy based non-contact type advanced machining process which can be applied for almost whole range of material (Avanish and Vinod, 2007). In laser beam machining, the material then melts, burns, vaporizes away, or is blown away by a jet of gas, leaving an edge with a high quality surface finish. It is suitable for geometrically complex profile cutting and making miniature holes in sheet metal (Avanish and Vinod, 2007). CO₂ and Nd: YAG laser are most established laser used for machining in industries.

At 1960's, C.K.N.Patel was carry the CO₂ laser pioneering experimental work at Bell Laboratories in the USA. Patel's first CO₂ laser, reported in 1964, relied on the rather inefficient lasing mechanism of pure CO₂ and output powers were in the range of 1mW (Powell, 1999). Within a year the output power had been raised to 10W as the result of adding nitrogen to the CO₂. Subsequent increases in power and efficiency were achieved by addition of helium to the mixture (Powell, 1999). The CO₂ laser cutting started at early 1970's as a method of cutting plywood to produce die-board for cartoon industries (Powell, 1999). Within a decade, improvement in optics, power and used of oxygen as cutting gas meant that CO₂ laser cutting was taken seriously as method of profiling metal (Powell, 1999).

LBM has wide applications in the field of automobile sectors, aircraft industry, electronic industry, civil structures, nuclear sector and house appliances (Avanish and Vinod, 2007). In the past few years CO₂ laser cutting of poly-hydroxyl-butyrates (PHB) was used in the manufacturing of small medical devices such as temporary stents, bone plates, patches, nail and screws (Avanish and Vinod, 2007).

This study is about the experimental studies of CO₂ laser beam cutting parameters such as laser output power, feed rate and assisting gas pressure to improve the process performance include surface roughness and kerfs width in mild steel 1020.

1.2 Background of Problem

The laser-cut surface shows a particular form of unevenness. The high degree of unevenness means the poor surface finish which occupies the high value of surface roughness. In the industries, the value of surface roughness is tried to minimize through a path of long way. Normally, the surface grinding process is applied to achieve the best value of surface roughness. Subsequently, the industry is necessary to modify their production line to reduce the product lead time and the number of highly skill machinist or machine operator will be definitely increased.

Kerfs width is the width of the cut path where the laser beam passes through the cut-zone of the material. The accuracy of the kerfs width value is very important as the dimensional error will occur if the kerfs width is over the limited value (over cut). The dimensional error workpiece of product will be reworked or recycled to overcome this problem. This is evidently wasting production time and cost to set-up the extra material recycles plant to reduce material misuse.

Nowadays, some of the industries are still applied the “trial” and “error” method to get the best setting of the laser beam machining parameters such as assist gas pressure, laser beam output power and feed rate. This inaccurate and inefficient method is cause to some wastes in time and material and do not guarantee the best result of quality respond. Hence that is why this study is carried out on CO₂ laser beam cutting for the parameters such as output power, feed rate and assist gas

pressure to improve the process performance include surface roughness and kerfs width in mild steel 1020.

1.3 Statement of problem

- What is the effect of Laser Beam Cutting process's parameters such as feed rate, output power and assisting gas pressure on surface roughness and kerfs width in mild steel 1020?
- What is the best setting for Laser Beam Cutting to achieve the best result of surface roughness and kerfs width?

1.4 Objective

- To analyze the effect of Laser Beam Cutting process parameters such as feed rate, output power and assisting gas pressure on surface roughness and kerfs width in mild steel 1020.
- To determine the best setting for Laser Beam Cutting to achieve the best result of surface roughness and kerfs width by using DOE.

1.5 Scopes

In this study, the factors that taken into account were feed rate, output power and assisting gas pressure. Meanwhile, the laser focal length, material thickness and cutting speed were not selected as the factor in this study. The quality responses that measured were included the surface roughness and kerfs width. The material that used in this study was mild steel 1020. The major technique applied to design the experiment was Response Surface Methodology (RSM).

1.6 Importance of study

By optimizing the parameter such as output power, feed rate and assisting gas pressure the surface roughness can be improved tremendously. This consequently eliminates the additional surface finishing processes which are costly to be maintained. Therefore, this can remove some of the workstations from the production line. Subsequently, this can shorten the production line where the lead time and production cost can be reduced and contributed more into the company earnings. By decreasing the kerfs width, the material utilization and accuracy of product dimension can be increase to reducing the waste of material and possibility of rework.

1.7 Expected result

The surface roughness and kerf width produced by laser cutting can be improved by controlling the main parameters such as laser power, feed rate and assisting gas pressure. The differences in the parameters value produce difference value of kerf width and surface roughness. Besides, by applying design of experiment (DOE) method, the optimum values of machining parameters of laser cutting obtained to minimize the value of surface roughness and kerf width.

CHAPTER 2

LITERATURE REVIEW

This chapter shows the basic principle, equipment and properties of CO₂ laser cutting. Besides, the material properties that affect the cutting speed, process parameter and quality response are explained. The summary for journal was shown at the end of the chapter to conclude the finding from the journals.

2.1 CO₂ Laser Cutting

Laser cutting is an advanced machining process that uses a laser to precisely cut patterns in many types of materials such as metal, plastic and wooden material. Laser cutters are used in a large variety of industrial applications due to the advantage of its cutting properties. Anonymous, 1998 state that laser with its increased flexibility, high level of accuracy and high quality cut, laser cutting is replacing conventional machining processes such as plasma and oxy-fuel cutting.

Anonymous, 1998 state that the gaseous CO₂ laser and the solid-state Nd:YAG laser are commonly used for cutting. CO₂ lasers work by "pumping" the atoms of the gaseous mixture into an excited state within the laser's chamber. Once the gas is pumped, it contains a collection of atoms with some electrons sitting in the excited state. The excited electrons relieve some of their energy by emitting photons. The state of the electron's energy when the photon is released is the determining factor of the wavelength (color) of the emitted photon. The light energy is amplified by being reflected back and forth multiple times within the laser's chamber. A laser cutter uses mostly a thermal process in which the light emerges from the laser's aperture and the beam is focused by a lens on to the surface of the material being cut. The laser beam

either melts burns or vaporizes the material in a localized area. The type of cutting process is depended on the type of the material used.

2.1.1 Basic principle

According to Powell, 1999 the mechanism of the CO₂ laser-cut is very simple. Firstly, the CO₂ laser beam is focused down onto the surface of the workpiece after passing through the focusing lens. If the material or the workpiece is high reflective, the material can be coated by using other low reflectivity material. Second, the focused beam will generate intense heat to melt the workpiece all the way via a very narrow region (normally ~0.3 mm or ~12 thousandths of an inch). If the material has the high thermal conductivity like aluminum and copper, the maximum material thickness that can be cut will be reduced. Third, the gas jet acting with the laser will pushes the melt out of the bottom of the cut zone. The erosion and the slug of the molten material will attach on the bottom area of the workpiece and affect the quality of the cutting zone. At the same time, during cutting certain materials the gas jet can react chemically with the workpiece to produce heat and accelerate the cutting speed. The most common application of this kind of cutting is cutting assisted by oxygen jet. Finally, the cut zone (laser head or the workpiece) is moved around the workpiece to produce the desired profile. The laser cut can perform any cut profile without limitation as laser cutting is a non contact profiling process.

2.1.2 Equipment

According to Powell, 1999, the infrared light generated by the CO₂ laser is invisible to the naked eye. In every other way it behaves as a normal light beam which can be reflected off mirrors and focused by lenses which made by using special material. The component of CO₂ laser cut and what happen to the metal sheet during the laser beam focused onto it are shown in the Figure 2.1 and 2.2 respectively.

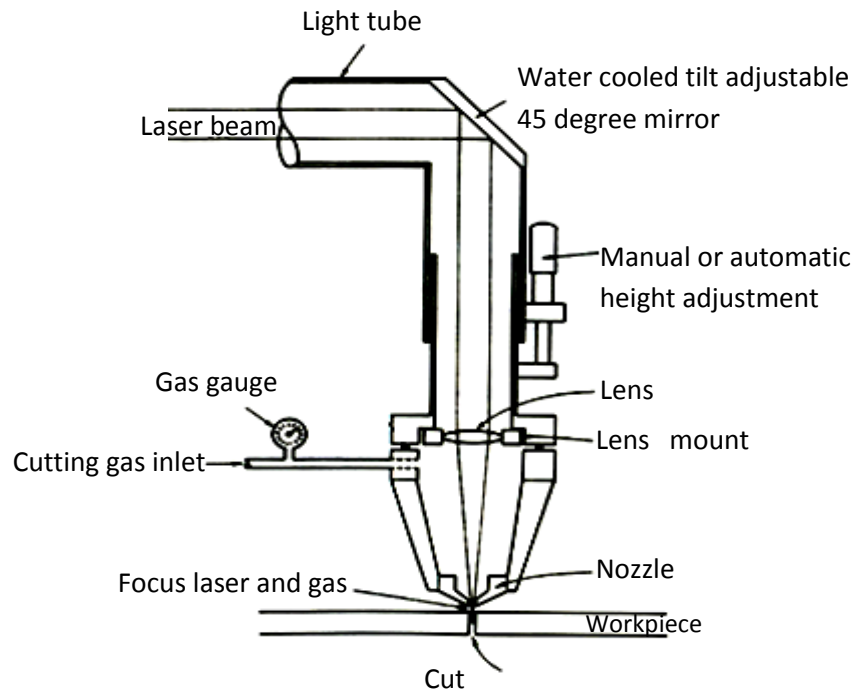


Figure 2.1: A schematic that shows the components of the CO₂ laser beam cutter.

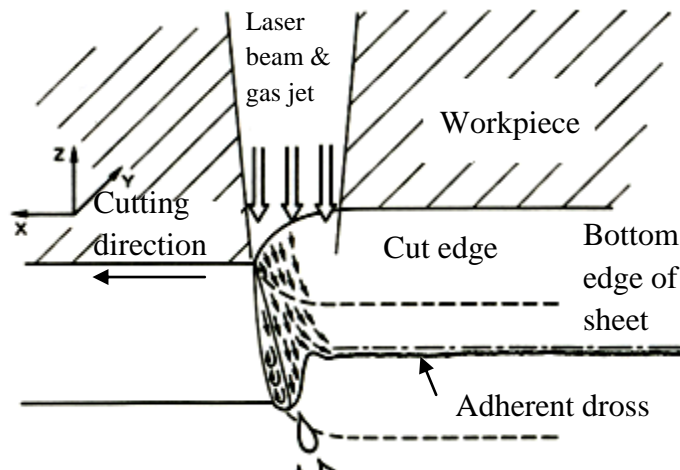


Figure 2.2: A schematic that shows what happens to the metal sheet during the laser beam focused onto it.

According to Powell, there are five main methods of moving a cut around the workpiece and they are shown as follows:

Moving optics system

Figure 2.3 demonstrates the principle of a machine which uses moving mirrors to reflect the laser beam to the cutting head. In this case the material remains stationary.

Moving workpiece

In the case, the laser cutting head remains stationary and the workpiece is moved.

Hybrid systems

A single moving mirror is used to move the laser beam in one direction and the material is moved in the other.

Moving laser system

The laser itself is moved over the workpiece with its cutting head.

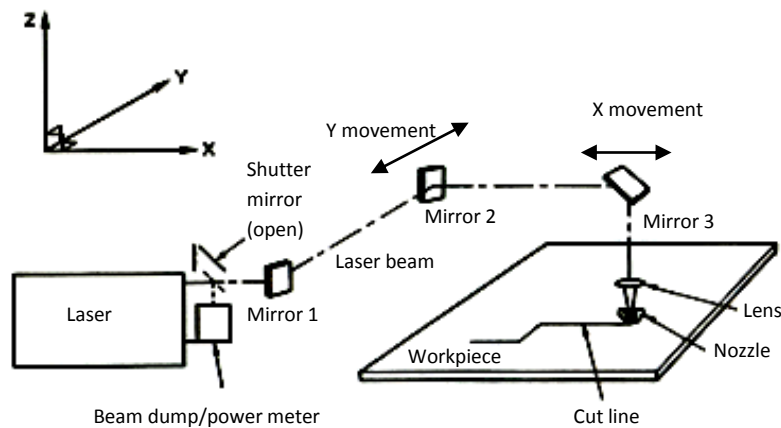


Figure 2.3: A schematic of a cutting table with moving mirrors in the X and Y axes.

Fiber optic system

These cannot be used with CO₂ laser but are appropriate for Nd:YAG lasers. In this case the light from the laser is piped down an optical fiber before being focused by a cutting head which is moved across the workpiece.

CNC or DNC control is always applied to the cut path and to add tool compensation to a chosen path and to control additional functions such as laser power nozzle gas pressure etc.

CO₂ laser power below 200 watts is generally only suitable for non-metals such as plastic, thermoplastic, wood based product etc. Meanwhile, the high CO₂ laser power which excess 5000 watts is generally used for welding or heat treatment as the low laser beam quality and is not suitable for cutting propose. The laser can produce two

types of energy stream which are the continuous stream and the pulse stream. Both types of output can be used for cutting and the pulsed beam cutting is suitable of the high degree of control or during cutting fine detail in steel.

2.1.3 Advantages of Laser Cutting

Benefits of laser cutting are discussed and summarized at the following:

1. The laser cut is the high speed process compared to other profiling methods. For example a typical 1200W CO₂ laser will cut 2 mm thick (0.08 in) mild steel at 6m/min (~240 in/min). The same machine will cut 5mm (0.2 in) thick acrylic sheet at ~12m/min (~480in/min).
2. The extremely narrow kerfs width is produced (normally 0.1 to 1.0mm). Able to perform the very detail work without limitation of minimum internal radius compared to the milling machines and similar mechanical method. Besides, the narrow cut width also minimizes the material waste where two components can “share” the cut line.
3. The LBC process is typically fully CNC controlled and lack of necessity for complex jiggling arrangement due to the non contact cutting of the laser cut process.
4. Usually, the cut path is ready for service immediately after cutting without any further cleaning operation.
5. The heat affected area is minimized and the thermal distortion is avoided because the actual area heated by laser is very small furthermore, most of this heated material is removed during cutting.
6. The running cost is generally low although the initial installation or set-up cost is high.
7. The process is very quiet compared to other machining techniques which able to improve the working environment and the efficiency of the operating staff.

8. The usage of laser cutting machines is extremely safe if compared to many other machining processes.

2.2 Material

The material selected in this study was the mild steel AISI 1020 due to the frequently application of this material in industry.

2.2.1 Mild steel AISI 1020 properties

AISI 1020 contents (0.18% to 0.23%C). These steels cannot be effectively heat treated, consequently there are usually no problems related with heat affected zones in welding. AISI 1020 do not contain chromium which makes it ductile with good forming properties. Nevertheless, this material shows spectacular effect on hardenability by adding chromium as low as 0.1% and vanadium and molybdenum contents as low as 0.05%. Generally, the thermal conductivity, coefficient of thermal expansion and electrical resistivity of the AISI 1020 are 51.9 W/m-K , $11.7 \text{ (}^\circ\text{C)}^{-1}$, and $1.60 \times 10^{-7} \text{ } \Omega\text{-m}$. According to the Huyett, the table of physical properties of the AISI 1020 is shown in the Table 2.1.

Table 2.1: The physical properties of the AISI 1020

AISI No	Treatment	Tensile strength (lb/in ²)	Yield strength (lb/in ²)	Elongation (%)	Reduction in area (%)	Hardness (Bhn)	Impact strength (Ft-lb)
1020	As-rolled	65,000	48,000	36.0	59.0	143	64.0
	Normalized (1600°F)	64,000	50,250	35.8	67.9	131	86.8
	Annealed (1600°F)	57,250	42,750	36.5	66.0	111	91.0