KOLEJ UNIVERSITI TEKNIKAL KEBANGSAAN MALAYSIA

Quality Investigation of Circular Laser Cutting

Thesis submitted in accordance with the requirements of the National Technical University College of Malaysia for the Degree of B. Manuf. Eng. (Honours) (Manufacturing Process)

By

Low Kah Huey

Faculty of Manufacturing Engineering

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KOLEJ UNIVERSITI TEKNIKAL KEBANGSAAN MALAYSIA

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SESI PENGAJIAN : 2005/ 2006

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APPROVAL

This thesis submitted to the senate of KUTKM and has been accepted as fulfillment of the requirement for the degree of B. Manuf. Eng (Honours) (Manufacturing Process). The members of the supervisory committee are as follows:

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Mr. P. S. Sivarao
Main supervisor
Faculty of Manufacturing Engineering

DEDICATION

For My Family Members.

ABSTRACT

Laser cutting is one of the most common types of laser material processing technology. It is a process of shaping or removing a work piece into desired geometry. It has become widely used in current industries due to its wider machining capability, flexibility and high precision in producing intricate and complex design part. Trepanning however is a process of internal contouring or hole making process on a work piece. There are geometrical errors (circularity & taper hole) which existed in most of the laser hole. This is an experimental based quality investigation on stainless steel (5 mm) with trepanned straight through 20 mm diameter hole using a maximum capacity of 3kW CO_2 laser machine. Pressure, frequency and duty cycle variation were made while maintaining the power at 2.7 kW and cutting speed at 800 mm/min which were set during the machining process. Nitrogen gas was used as assisted gas. Conical nozzle with diameter 2.0 mm was used and maintained at stand-off distance (SOD) of 1 mm above the work piece. A lens with focal length 7.5" was used to focus laser beam at focal distance (FD) 3.0 mm downwards from material surface. The quality investigations focus on the straightness and circularity which aims in obtaining minimum tolerance of hole for mating part purpose. The quality investigation was performed using WENZEL LH 54 CMM machine and calculations of straightness and circularity was done manually according VOLVO corporate standard, STD 5062, 2E.

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LIST OF ABBREVIATIONS, SYMBOLS, SPECIALIZED NOMENCLATURE

%	-	percent
&	-	and
”	-	inch
<	-	less than
>	-	more than
±	-	plus minus
≈	-	almost equal to
®	-	Right
3D	-	three dimensional
A	-	Absorption
angstroms	-	measure of length, 1 angstrom= 10E-10m
ANOVA	-	Analysis Of Variance
ANSI	-	American National Standard Institute
b.	-	born
Cm	-	centimetre
CO_2	-	Gas Carbon Dioxide
CVL	-	Copper Vapor
Cw	-	clock wise
CW	-	Continuous Wave
D	-	Diameter
D.O.E	-	Design of Experiment
DC	-	Duty Cycle
DIN	-	Deutsche Industry Norm
E	-	Energy per Pulse
e.g.	-	example
EB	-	Electron Beam
EDM	-	Electro Discharge Machining

EF	-	Electro-forming & Plating
etc.	-	Exedra/ and others
F	-	Frequency
F.D.	-	Focal Distance
FKP	-	Manufacturing Engineering Faculty (Fakulti Kejuruteraan Pembuatan)
GP	-	Gated Pulse
H_2	-	Gas Hydrogen
HAZ	-	Heat Affected Zone
He	-	Gas Helium
Hz	-	Hertz
in.	-	inch
IPTA	-	The higher Public Education *(Institute Pengajian Tinggi Awam.)*
ISO	-	International Organization for Standardization
J	-	Joule
JIS	-	Japanese International/ Industry Standard
K	-	Kelvin
K	-	kilo
Kg	-	Kilogram
KUTKM	-	Kolej Universiti Teknikal Kebangsaan Malaysia
L	-	Length
LASER	-	Light Amplification by Stimulated Emission of Radiation
M	-	meter
mA	-	Mili Ampre
MB	-	Mega Byte
Mil	-	1 mil = 0.254 mm
mJ	-	mili Joule
Mm	-	millimeter
Mn Cr V_4	-	Manganese Chromium Vanadium
Mpa		Mega Pascal
N		Nominal value
N_2	-	Gas Nitrogen

NC	-	Numerical Control
Nd:YAG	-	Neodymium Yttrium Aluminium Garnet
Nm	-	nanometre
No	-	number
^{o}	-	Degree
ø	-	Diameter
O_2	-	Gas Oxygen
p	-	Pressure
P	-	Power
Pa	-	average power
P_p	-	peak power
ps	-	Pico second
PSM	-	Project of Bachelor *(Projek Sarjana Muda)*
R	-	Radius
R	-	Reflectivity
RF	-	radio-frequency
s	-	seconds
SOD	-	Stand Off Distance
STD.		Standard
T	-	Transmissivity
t	-	thickness
TEA	-	Transversely Excited Atmosphere Pressure
UV	-	Ultra violet
V	-	volt
W	-	Watt
WJ	-	Water jet
δx	-	Maximum deviation
λ	-	Wave length symbol
μm	-	micro meter
Σ	-	total
τ	-	Pulse width symbol

CHAPTER 1
INTRODUCTION

1.1 Project Introduction

It is compulsory for all the undergraduate KUTKM students to carry out a project related to their field of studies in their final year before graduation. With this given opportunity, a project has been carried out based on the selected topic in order to fulfill the requirements of graduation.

The studies on "Quality Investigation of Circular Laser Cutting" which is an experimental based research. The project was assisted by lecturer, Mr. P. S. Sivarao. This study was proposed to be carried out due to the existing weaknesses of laser machining. The most frequent usage of this application is in mechanical, automotive, aerospace and electronic industries.

Based on the research title, quality investigation was carried out to collect and record related quality checking results of laser machining process. This project will be continued using different material and machining parameter settings in the future to produce a complete result records for future machining reference. The experimental results in this project are among the data that recorded in the reference. In the experiment, quality investigations were focused on straightness and circularity of the trepanned hole for different parameters setting.

1.2 Background

LASER beam is a coherent light which enables production of high energy source to accomplish many kinds of different fields of works. Along the past several decades since it had been invented, laser has benefited mankind tremendously in many fields such as in science, medical therapy, material processing, manufacturing, electrical and electronic, aerospace, maritime, telecommunication and entertainment. Laser applications comprised of laser surgery, metal & nonmetal cutting, making holograms, measurement, radar detection, fiber optics, electronic components welding and others. The invention of laser has become an invaluable tool for mankind to carry out uncountable works that had been unable or hard to be done before. Thus, laser has opened up new doors for future scientific researches and technology development with the aims on improving human live.

Laser has several usage in manufacturing and mechanical engineering such as welding, percussion drilling, cutting, marking, etching, alloying & cladding, surface treatment and many more. Hole or internal profiling produced using laser machine is called trepanning process. It is another important and popular application after linear cutting. Some of the lasers cutting products are lift panel, machine panel, automotive components, gear, product casing, decorative lamp pose and gate which required high dimensional accuracy and surface finish for fitting purpose. Precise, intricate pattern, repeating array design, lower thermal effect on cutting part is able be produced easily unlike conventional methods which has a higher difficulty level.

1.2.1 Basic Concept of Laser Cutting

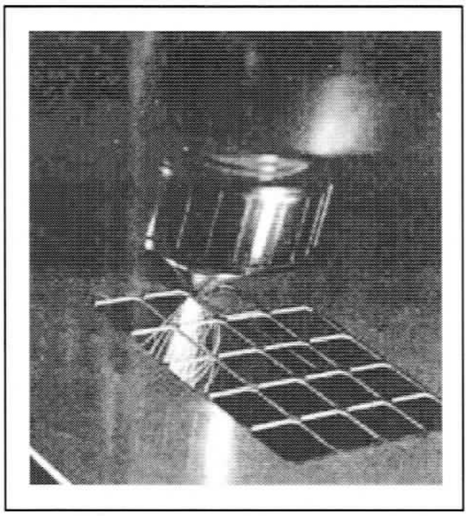

Figure 1.2.1 Laser cutting of stainless steel 0.020 in thick with high power CO_2 laser. (Ready, J.F., 1978)

Laser machining can be divided into one dimensional, two and three dimensional processes by differentiating the kinematics of erosion front during the beam or material interaction. The entire laser machining processes shows common characteristics such as molten layer formation, plasma formation and beam reflection from the erosion front. The characteristics such of laser cutting process areas stated below:

- Laser machining is a thermal process. The effectiveness of the process depends on the thermal properties of the machined material.
- Laser machining is a non-contact process. It eliminates mechanically material damage, tool wear and machine vibration. The machine removal rates are also not limited by maximum tool force, built up edge formation or tool chatter.
- Laser machining is a flexible machining process. It easily combines with automated system which can be used for application such as welding, grooving, drilling and milling.

Generally, laser cutting is considered as a two dimensional process in which material removal occurred by moving the laser source in a direction perpendicular surface, therefore two laser cutting by moving the line source to another dimensional direction.

1.2.2 Applications on Cutting & Comparisons with Other Technologies

A wide range of material can be cut using laser. The materials are includes paper, wood, cloth, glass, quartz, ceramic, composite and mostly metal cutting. Laser cutting is fine and precise. It introduces minimum mechanical distortion and thermal shock in the material being cut. Furthermore, the process does not introduce any contamination. It is easily automated and high production rate can be achieved.

The power required for cutting depends on the material to be cut. Plywood can be cut with an 8 kW CO_2 while metals are cut with 100 to 500 W output power. CO_2 laser prepares to cut pieces for 50 suits during an hour.

Laser cutting is facing tight competition with punching technology especially on thin material up to thickness 6 mm. Laser is the superior choice for small series parts and parts with difficult contours. Besides that, laser cutting applied mostly in producing fine mating parts such as panel of lift, machine, toll stand and so on. Figure 1.2.2a and b show comparison of laser cutting with other cutting technologies.

LASER CUTTING	PUNCH PRESS
Advantages	*Advantages*
- no tools required	- high production and low costs
- smooth change-over to other products	- for large and medium series of production
- complex contours are possible	- lower initial investment
- short set-up times	- forming operations possible
- minimal loss of material	
- narrow laser cut	
- optimal nesting possibilities	
- cuts through hard steel	
- no burrs	
- low noise	
- no deformation	
Disadvantages	*Disadvantages*
- slower	- high investment for tooling
- higher initial investment	- wear of tools
- high consumption of energy	- relatively long set-up times
	- noisy

Figure 1.2.2a Comparison of Laser cutting and Punching
(Dr. Serruys, W., 2002)

thermal cutting	Flame cutting	plasma cutting	laser 3kW	Laser 6kW
energy source	oxidation	plasma	light	light
energy density	low	medium	high	high
suitable material	steel	—— steel, stainless steel, aluminum ——		
cutting speed	low	high	medium	medium
cutting 12 mm steel	500 mm/min	2700 mm/min	1400 mm/min	2100 mm/min
width cutting edge	medium	large	small	small
cutting 12 mm steel	1,5 mm	3 mm	0,5 mm	0,8 mm
dimensional accuracy	1 a 2 mm	0,5 a 1 mm	0,2 mm	0,2 mm
linearity of a 30 mm strip	1,5 mm/m	3 mm/m	0,4 mm/m	0,4 mm/m
squareness of cutting edge	good	bad	good	good
surface finish	reasonable	good	reasonable	reasonable
melting upper edge	reasonable	bad	good	good
cutting with multiple heads	easy	max 4	difficult	difficult
unguarded operation	reasonable	reasonable	appropriate	appropriate
environmental pollution	reasonable	high	low	low
investment	low	medium	high	high

Figure 1.2.2b Comparison of Laser Cutting with Flame Cutting & Plasma Cutting
(Dr. Serruys, W., 2002)

1.3 Problem Statement on Laser Cutting

Although laser is considered the finest machining process that can be chosen in metal cutting, this method however still consists of avoidable defects on its cutting edge. The problems that always occur are taper cutting edge and lack circularity of hole. Taper and less circularity of hole are due to intensity looses of laser beam from entrance to exit hole while penetration process. There is some tolerance of circular shape which requires to determine if the part is used for fitting purpose.

The unavoidable defects also including parallelism of both holes edge, the center point of diameter hole is offsetting from center line as the hole penetrates deeper, which is shown in Figure 1.3a. The cross section of a kerf is shown in Figure 1.3b, in which the hole entrance has larger diameter but decrease with the increase of hole depth. This problem is noticeably obviously when machining thicker material or higher ratio of diameter-to-thickness of material. In Handbook of Laser Material Processing written by Ready, J.F., he said that the taper shape is caused by loss of beam intensity, defocusing or loss of gas pressure across the thickness of the cut but others said it happens because there is no gas jet system in cutting nozzle head.

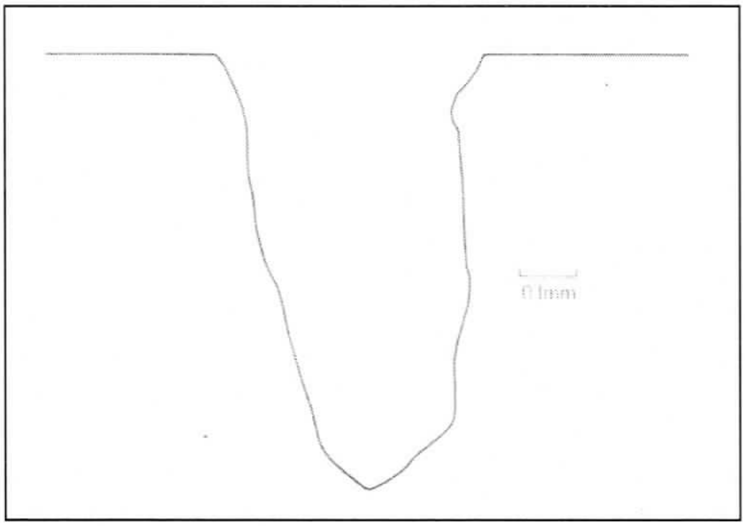

Figure 1.3a Cross section of hole produced in massive brass by a 5 J pulse from an Nd: glass laser (Ready, J.F., 1978)

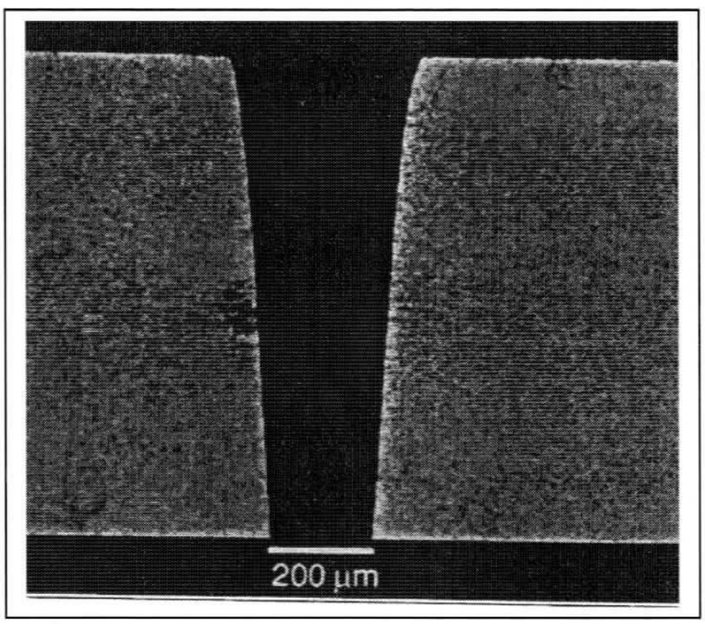

Figure 1.3b Cross section of laser holes edge (Ready, J.F., 2001).

These problems are trying to be reduced by carrying out additional machining process or required skilled machinist in operating machining settings. It is because the machining performance also depends on different material composition and machining condition.

Meanwhile, cutting edge of surface is also not smooth enough as had shown in Figure 1.3c. Dross or the recast material may be attached to the under lip of the hole and recast metal may protrude at the top which display a crater-like lip for the hole which make the roughness of the surface worsen. This problem arises because the material rarely vaporized completely in metal or not fully ejected by gas jet. Sometimes, when the molten material is not fully ejected from the bottom holes, it will easily recast on the first cool surface that it strike. Although the dross under lip is easily removed by shot blasting or light grinding, the recast material on the top is hard and an integral part of the remaining metal.

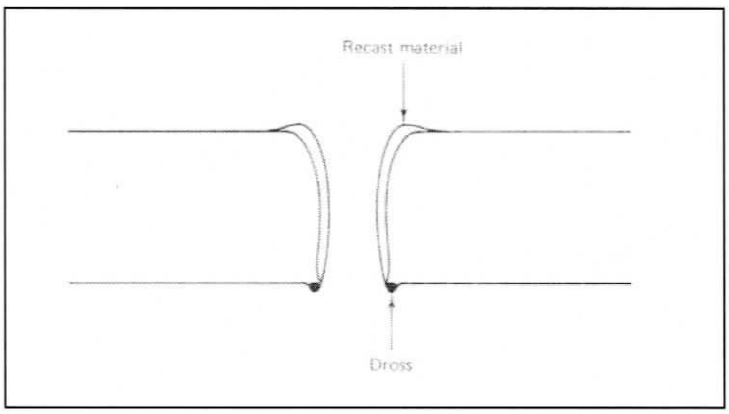

Figure 1.3c Dross and Recast Material on Kerf Surface.
(Luxon, J.T & Parker, D.E., 1976)