UNIVERSITI TEKNIKAL MALAYSIA MELAKA

High Performance Laser Drilling on Stainless Steel

This report is submitted in accordance with the partial requirement of the Universiti Teknikal Malaysia Melaka for the Bachelor of Manufacturing Engineering (Manufacturing Process and System)

By:

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (*Manufacturing Process and System*). The member of the supervisory committee is as follow:

<u>**Dr. Bagas Wardono**</u>

(Main Supervisor)

ABSTRACT

LASER stands for Light Amplification by Stimulated Emission of Radiation. Drilling is one of the most important and successful applications of industrial lasers. Laser drilling of metals is used to produce tiny orifices in the workpiece by removing material to create through holes. However in this study, the focus was on the high performance laser drilling by removing a certain amount of workpiece by conducting trepanning process on stainless steel. In this laser drilling process, the quality of drilled holes was evaluated. A thorough study of the process variables on the quality of the holes produced was performed. In present study, the laser parametric effects and the machining characteristic of surface roughness, R_a on the hole quality after the drilling process run are examined. A statistical approach, referred to as factorial design, given a value of significant level, alpha = 0.05 (95% confidence level) is used to test the parameters combinations that affect the hole quality and surface characteristic. For this experimental study, a two level full factorial design were used to examine the influence of parameters combinations on hole quality. The surface roughness is evaluated by measuring the value of R_a on top and bottom side of surface for each holes produced using combination variables of frequency, speed, and pressure. ANOVA result was generated by Minitab v14 using these measurements data and some graphs were plotted in order to find the main effects which is significant. Finally, the significant main effects were optimized in order to find the suitable process parameters values or level combination in producing good quality holes with good surface roughness.

ABSTRAK

LASER ditakrifkan sebagai Light Amplification by Stimulated Emission of Radiation. Penggerudian merupakan suatu proses yang amat penting dan selalu diaplikasikan dalam industri laser. Penggerudian laser ke atas bahan besi merupakan proses menghasilkan lubang kecil yang tembus terhadap bahan kerja dengan membuang sebahagian daripada bahan besi tersebut. Akan tetapi, di dalam kertas kerja ini, penumpuan akan diberikan kepada keberkesanan penggerudian laser dengan mengunakan cara '*trepanning*' proses ke atas *stainless steel*. Dalam kajian ini, kualiti lubang-lubang yang dihasilkan akan dinilai. Ciri pemesinan seperti kekasaran permukaan, R_a pada lubang selepas proses penggerudian turut dikaji. Satu kajian mendalam akan dijalankan terhadap parameter-parameter yang menghasilkan lubang-lubang tersebut dengan pedekatan statistic menggunakan *two-level factorial design*. Nilai alpha = 0.05 (95% *confidence level*) digunakan bagi menguji keberkesanan gabungan parameter yang digunakan sama ada mengpengaruhi kualiti lubang dan juga ciri-ciri permukaan bahan kerja. Ukuran kekasaran permukaan akan diukur pada permukaan sebelah atas dan sebelah bawah lubang-lubang yang dihasilkan daripada gabungan parameter seperti frekuensi, tekanan gas, dan kadar pemotongan. Selepas data diambil, keputusan ANOVA akan dijana dengan software Minitab v14, dan graf-graf yang berkenaan akan diplotkan untuk mencari kesan utama yang signifikan. Berdasarkan kesan-kesan utama signifikan ini, kerja analisa akan dijalankan untuk mencari nilai parameter proses atau gabungan parameter yang paling sesuai bagi menghasilkan lubang berkualiti tinggi dengan kekasaran permukaan yang rendah.

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LIST OF ABBREVIATIONS, SYMBOLS, NOMENCLATURES

ANOVA	-	Analysis of Variance
ANSI	-	American National Standards Institute
ASTM	-	American Society for Testing and Materials
cw	-	Continuous wave
DOE	-	Design of experiment
EDM	-	Electrical discharge machining
HAZ	-	Heat affected Zone
LASER	-	Light Amplification by Stimulated Emission of Radiation
LMP	-	Laser Machining Process
Nd	-	Neodymium doped
PSA	-	Pressure swing absorption
TEM	-	Transmission electron microscopy
UV	-	Ultraviolet
VPSA/VSA	-	Vacuum pressure swing adsorption
YAG	-	Yttrium Aluminium Garnet

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Laser machining means material removal accomplished by laser material interaction, generally speaking, these processes include drilling, cutting, grooving, and marking or scribing. Before we proceed into the details of laser machining processes (LMP), we need to know what are the features of LMP and when do we choose LMP instead of tradition machining processes [3].

Laser machining processes transport photon energy into target material in the form of thermal energy or photochemical energy; they remove material by melting and blow away, or by direct vaporization/ablation. On the other hand, traditional machining processes rely on mechanical stresses induced by tools to break the bonds of materials. This basic difference in material removal mechanism decides the advantages and disadvantages of LMP compared with traditional machining processes [3].

1.2 Problem Statements

Mechanism describing laser machining require a knowledge of the interaction mechanisms as well as the physical properties of the substance being drilled, such as thermal diffusivity, surface reflectivity, absorption coefficient, and etc. These properties are often unknown at the elevated temperatures resulting from laser beam heating. Therefore, a model describing the drilling process has not yet been fully established [1].

Yilbas [1], stresses out for the application of laser beam used in micromachining, various factors must be considered and evaluated. These factors include the laser pulse length, the pulse energy, the focus settings of the focusing lens, and the work piece thickness and thermal properties. Effective utilization of the laser depends very much upon the proper selection and optimization of these factors. Limited information on how these factors affect the laser-drilled hole quality have seriously hindered the growth of laser applications in micromachining, because the effects of some of these factors have been underestimated previously. Therefore, a systematic study to establish and recognize the machining standards to produce holes with good quality is necessary.

There are various research objectives that have been performed by researchers in the past. One of them is the repeatability of laser producing holes. The fact shows that it is often difficult to produce repeatable holes with laser percussion drilling. This makes the process of fabricating holes with desired hole geometry to the industrial tolerances difficult to achieve. Figure 1.1 illustrates a set of three holes drilled with the same laser parameters and yet the hole geometry is different from one hole to another. In view of this, it becomes necessary to understand the characteristics of repeatability [2].

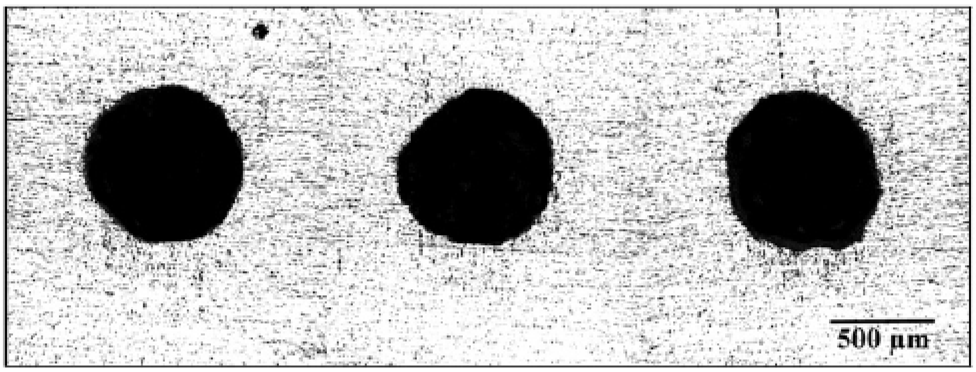

Figure 1.1: Variation of entrance geometry of laser percussion drilled holes under the same operating parameter setting [2].

Other topics involving LMP include cutting, grooving, and marking or scribing. In laser cutting, laser can separate workpieces along lines or curves, such processes are called laser cutting processes. Thin workpieces may be difficult to cut by other means, while laser cutting is suitable because of it noncontact feature. Lasers have been used to cut a wide range of materials. CO_2 laser and Nd:YAG laser are the most popular laser in cutting, they can provide high powers (above 1 kW) for high speed cutting. Ultraviolet (UV) lasers are widely used for thin layer cuttings or organic material cutting. Gas jet is often used to improve the cutting efficiency. Laser marking, scribing and texturing refer to laser machining of material surfaces, usually a very shallow layer of material is ablated or melted and a mark or pattern is formed. Laser grooving is similar to laser cutting except that grooving does not cut through the material [3].

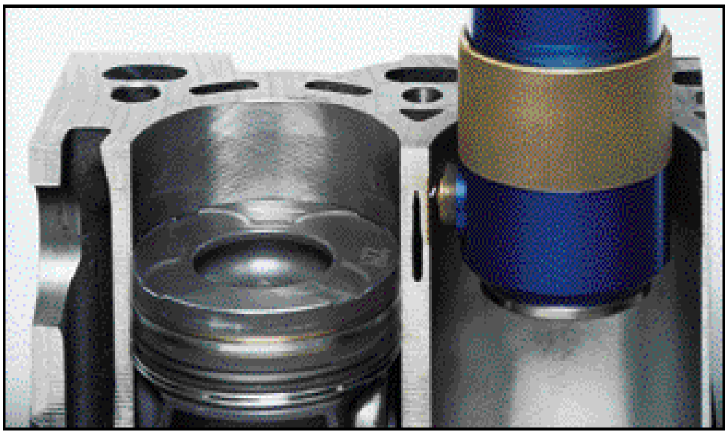

Figure 1.2: Laser texturing of engine cylinder walls [3].

In our study, we are going to focus the research study on high performance of laser drilling on stainless steels by conducting a design of experiment using the most suitable design methods available.

1.3 Objectives and Aims of Study

1) To gain basic knowledge on advanced machining using laser system.
2) To learn the basic principles on the laser operating system.
3) To identify the parameters used in laser drilling process.
4) To determine the basic machining characteristics such as surface roughness.
5) To apply statistical analysis such as design of experiment (DOE) using suitable design method to select the optimal machining conditions for good hole quality.

1.4 Scopes of Study

The scope of this study will be designing an experiment for the high performance of laser drilling on stainless steel by using the parameters or variables that can be adjusted with the available laser machine in our laboratory. Geometry of the drilled hole will be evaluated and discussed further in order to improve the quality of drilled hole through optimization of these parameters through design of experiment (DOE).

CHAPTER 2

LITERATURE REVIEW

2.1 Fundamental Principle of Laser

The word *laser* is an acronym for Light Amplification by Stimulated Emission of Radiation. A laser device is a light source that amplifies light and produces a highly directional, high-intensity beam that most often has a very pure frequency or wavelength. It comes in sizes ranging from approximately one tenth the diameter of a human hair to the size of a very large building, in powers ranging from 10^{-9} to 10^{20} W, and in wavelengths ranging from microwave to the soft-X-ray spectral regions with corresponding frequencies from 10^{11} to 10^{17} Hz. Laser have pulse energies as high as 10^{4} J and pulse durations as short as 5×10^{-15} s. The beam of light generated by a typical laser can have many properties that are unique. When comparing laser properties to those of other light sources, it can be readily recognized that the values of various parameters for laser light either greatly exceed or are much more restrictive than the values for many common light sources. "A laser is a specialized light source that should be used only when its unique properties are required" [4].

The starting process in laser materials processing is always the absorption of a raw or focused laser beam at surface of the workpiece. The beam is usually incident normal to the surface of the workpiece. This absorption is determined by the absorptivity and reflectivity of the material. Metals, for example, absorb an increasing fraction of the beam power as the wavelength decreases from the 10.6µm of CO_2 lasers to 1.06µm of Nd:YAG lasers and to the 0.8-1.0µm of diode lasers. For material hardening the surface shape does not change during processing and data taken can give a direct measure of how efficiently laser power can be used. In this case the shorter wavelength lasers are preferable due to their higher absorptivity.

The second stage of laser material processing is the transfer of heat into the workpiece by conduction. This is illustrated in Figure 2.1. In the initial phase the heat-flow is nearly one dimensional into the depth of the workpiece. Lateral heat conduction, which can be viewed as a loss mechanism, is negligible. However, at longer period, the isotherms turn into three dimensional forms. The absorption zone can then be thought of as a point source with large lateral heat conduction losses. The lager the spot size and the smaller the thermal diffusivity, the longer the process can be regarded as being in the one dimensional case [9].

Atoms and molecules have determinate energetic levels, which can be low or high. The low energetic levels can be *excited* at high levels, generally by heating. Once they reach the energetic superior levels, they go back to the original state, and they return energy in a light form.

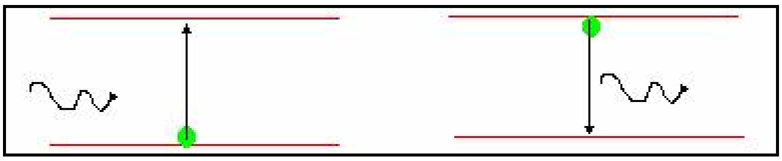

Figure 2.1: Initial phase [9].

Under normal conditions, the atoms proportion in low energetic levels in a body is bigger than that of the atoms that are found in superior levels, by this reason, any luminous beam that crosses a body loses energy, since part of its photons are absorbed when crossing.

In most cases the sources of ordinary light which comes from atoms and excited molecules and the light emission is done in various wavelengths (and frequencies). But, if during the short instant an atom is excited, the atom is influenced by light of a certain wavelength, this atom can be stimulated to launch radiation that is in phase with the wavelength that has stimulated it as shown in Figure 2.2.

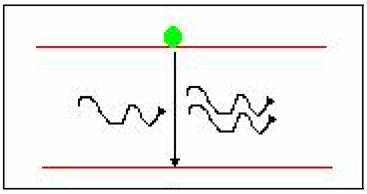

Figure 2.2: Intermediate phase [9].

The new emission increase, that is to say, amplifies the wave. If the phenomenon can be multiplied, we arrive to the fact that the percentage of atoms with high energy levels will be superior to the percentage of atoms in normal state. This phenomenon is known as population *inversion* shown in Figure 2.3.

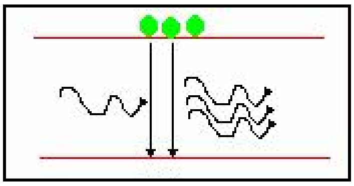

Figure 2.3: Emission phase [9].

Then, the resulting beam is a coherent light beam and it can be high-powered. The possibility of stimulating the radiation was already anticipated by A. Einstein in 1917, but the devices to build them were not created till the 1950s [9]. Figure 2.4 below shows the simple setup of an optical pumped laser.

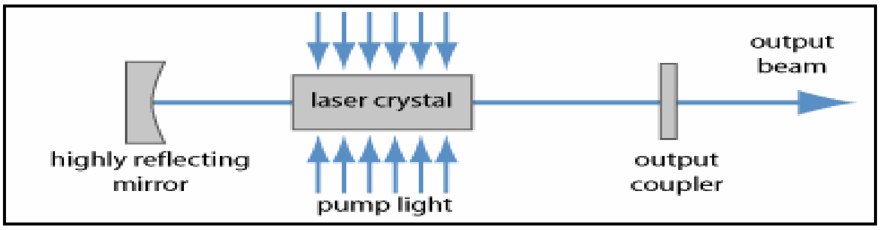

Figure 2.4: Setup of a simple optically pumped laser [9].

2.2 Laser Drilling

In laser drilling, a short laser pulse with high power density feeds energy into the workpiece extremely quickly, causing the material to melt and vaporize. The greater the pulse energy is the more material is melted and vaporized. Vaporization causes the material volume in the drilled hole to increase suddenly, creating high pressure. The vapour pressure expels the molten material from the hole. Spatter and vapour shoot upward in the direction of the processing optics. Once the laser beam breaks through to the other side, the spatter and vapour exit through the bottom. To prevent damage to the processing optics, manufacturers design the machines so that there is a large distance between the optics and the workpiece. A coaxial gas flow can also be used to shield the optics from spatter [10].

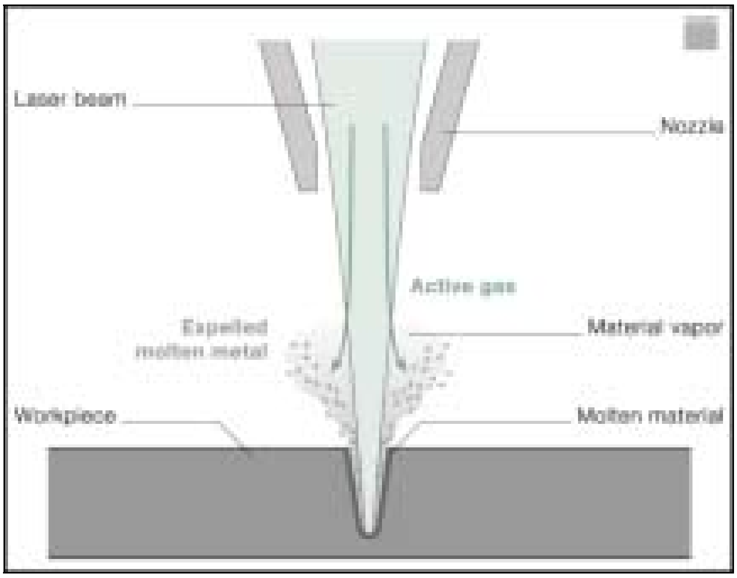

Figure 2.5: The laser drilling operation; the laser melts and vaporizes the material. The vapour pressure expels the molten material out from the hole.

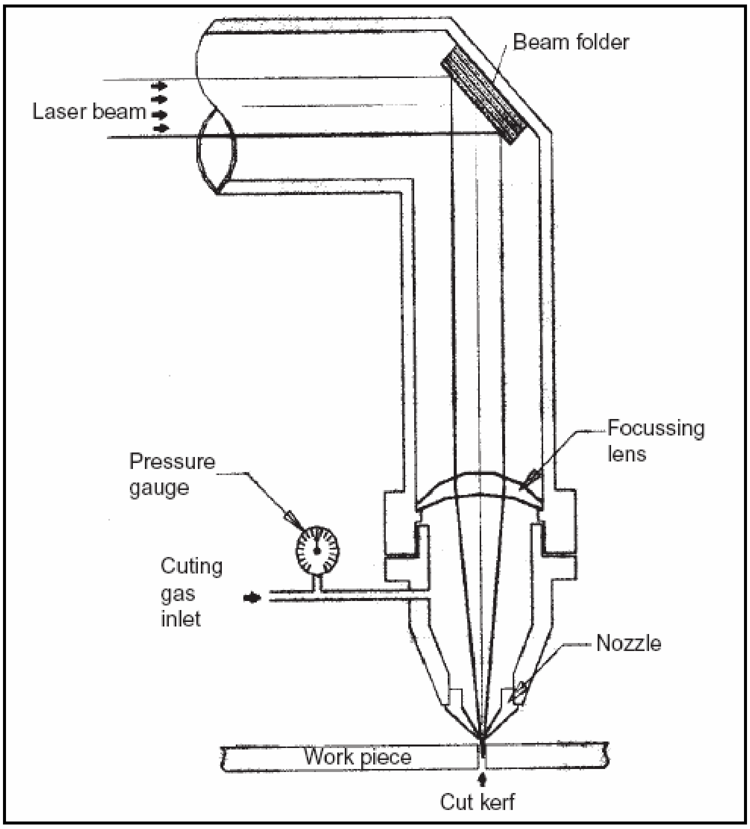

Figure 2.6: Basic Diagram of Laser Cutting Operation [7]

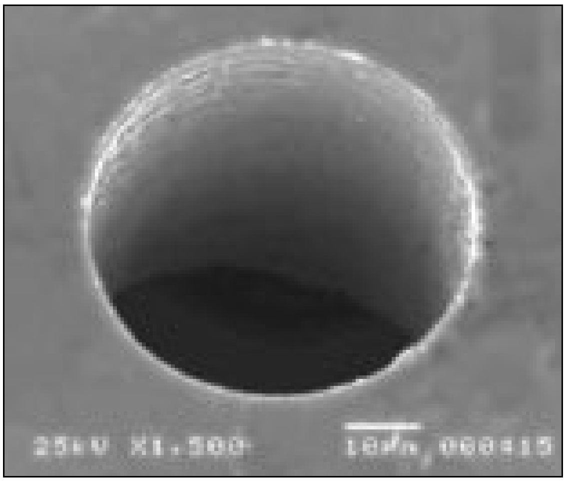

Figure 2.7: 150 micron diameter hole in silicon [16]

2.3 Types of Laser

Common types of lasers are [11]:

- Semiconductor lasers (mostly laser diodes), electrically (or sometimes optically) pumped, efficiently generating very high output powers (but typically with poor beam quality), or small powers with good spatial properties (e.g. for application in CD and DVD players), or pulses (e.g. for telecom applications) with very high pulse repetition rates.

- Solid state lasers based on ion-doped crystals or glasses, pumped with discharge lamps or laser diodes, generating high output powers, or lower powers with very high beam quality, spectral purity, and/or stability (e.g. for measurement purposes), or ultrashort pulses with picoseconds or femtosecond durations. Common gain media are Nd:YAG, Nd:glass, Yb:YAG, Yb:glass, Er:Yb:glass, Ti:sapphire, Cr:YAG, Cr:LiSAF, and Cr:LiCaF.

- Fiber lasers, based on optical glass fibers which are doped with some laser-active ions in the fiber core. Fiber lasers can achieve extremely high output powers (up to kilowatts) with good beam quality, allow for widely wavelength-tunable operation, narrow line width operation, etc.

- Gas lasers (e.g. helium-neon lasers, CO_2 lasers, and argon ion lasers) and excimer lasers, based on gases which are typically excited with electrical discharges. Frequently used gases include CO_2, argon, krypton, and gas mixtures such as helium/neon. Common excimers are ArF, KrF, XeF, and F_2.

Less common are chemical and nuclear pumped lasers, free electron lasers, and X-ray lasers [12].