Your complimentary
use period has ended.
Thank you for using
PDF Complete.
Click Here to upgrade to
Unlimited Pages and Expanded Features

N OF CUTTING PARAMETERS FOR CO_2 LASER BEAM CUTTING USING VARIABLE WEIGHT GREY-TAGUCHI METHOD

KHAIRUL FIKRI BIN MUHAMAD

IJAZAH SARJANA KEJURUTERAAN (PEMBUATAN)

UNIVERSITI MALAYSIA PAHANG

Your complimentary use period has ended. Thank you for using PDF Complete.

Click Here to upgrade to Unlimited Pages and Expanded Features

ABSTRACT

Carbon Dioxide (CO_2) laser beam cutting (LBC) process involves several parameters. These parameters need to be optimized in order to get the best quality output. Researchers had applied various types of optimization methods which are used for single or multi-objectives problems. One of the methods is Grey-Taguchi method. However, there is a disadvantage of these methods. This study focuses on improving the Grey-Taguchi method in order to optimize machining parameters for CO_2 LBC. The Variable Weight Grey-Taguchi method is proposed which considering all possible weights to be assigned to the control and noise factors. The considered control factors are stand-off distance, cutting speed and laser power. This study also considers surrounding temperature as noise factor. The superior of these methods is merely depending on the response factors which are Surface Roughness (SR), Kerf Taper Angle (TAP), Heat Affected Zone (HAZ) and Kerf Width (KW). Results from Matlab assisted physical experiment shows there is an effect on weight assigning to the factors. Results also show that the proposed method successfully improved all the response factors. Surface roughness had improved by 49.4%, taper 52%, Heat Affected Zone (HAZ) 9.3% and kerf width 46.2%. As conclusion, this study had successfully proposed an improved optimization method for LBC process.

Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

TABLE OF CONTENTS

Your complimentary use period has ended. Thank you for using PDF Complete.

Click Here to upgrade to Unlimited Pages and Expanded Features

PDF Complete
Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

RIMENTS ON CO_2 LASER BEAM CUTTING

Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

LIST OF TABLES

PDF Complete
Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

LIST OF FIGURES

Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

CHAPTER 1

INTRODUCTION

1.1 RESEARCH MOTIVATION

Referring to Malaysia Third Industrial Master Plan (IMP3) 2006-2020 that was published by the Ministry of International Trade and Industry (MITI) on August 16th 2006 (MITI 2006), Malaysia economy was ranked 8th among 30 countries in the category of populations above 20 millions. In order to sustain the achievement and enhancing Malaysia industrial capabilities, ten strategic thrusts had been set which are;

1. enhancing Malaysiaôs position as a major trading nation,
2. generating investment in growth areas,
3. integrating local companies into region and global networks,
4. ensuring more balanced regional development,
5. strengthening manufacturing sector,
6. developing service sector to become a major source of growth,
7. growing the knowledge-intensive technologies,
8. developing innovative and creative human capital,
9. strengthening the role of private sectors and
10. creating more competitive business.

IMP3 had outlined the fifth strategic thrust - the manufacturing sector as one of major sources of growth. There are some strategies to continuously develop this sector. One of the strategies is to support the applications of advanced manufacturing

Your complimentary use period has ended. Thank you for using PDF Complete.

Click Here to upgrade to Unlimited Pages and Expanded Features

ke biotechnology, nanotechnology, wireless technology, micro-electro-mechanical system, fuel cells and laser technology.

In addition, IMP3 also stated that machinery and equipment shall play an important role since it has direct linkage with major economic sectors like automotive, manufacturing and construction. This is indicated by the increased number of machinery and equipment manufacturers in operations from 118 manufacturers in 1995 to 410 manufacturers in 2005 during the IMP2 period.

IMP3 grouped machinery and equipment industry in Malaysia under four categories. The categories are:

1. power generating machine and equipment, including turbines, engines, power plants and boiler.
2. specialized machinery and equipment for specific industries, such as oil and gas, agriculture and plastic processing.
3. general industrial machinery and equipment including elevators, cranes, pressure vessels and construction machinery and equipments.
4. metalworking machinery and equipment which include:
    - metal-cutting computer numerical control (CNC) machine tools, such as CNC milling, CNC lathe and electro-discharge machine (EDM) and
    - metal-shaping and sheet-metal machine tools such as turret punches, laser cutting machines and shearing machines.

Based on the fifth category of strategic thrusts and the fourth category of machinery and equipments, research on laser technology and sheet-metal processing is strongly relevant to strengthen Malaysian economy towards realizing the Vision 2020. This is the research motivation.

1.2 RESEARCH PROBLEM STATEMENT

Laser is an acronym for Light Amplification by Stimulated Emission of Radiation. Since the introduction of first laser by Maiman on 1960, laser technology is rapidly

Your complimentary use period has ended. Thank you for using PDF Complete.

Click Here to upgrade to Unlimited Pages and Expanded Features

ique properties of laser are the main advantage in laser machining process.

One of the special properties of laser light is nearly collimated. So, laser beam can be focused on a very small spot. This is an important feature in laser machining, especially the laser cutting processes. Using laser beam as a cutting tool, cutting process is precise because laser beam is focused on a very small area resulting in high concentration of heat transfer from laser beam to the workpiece.

Despite laser beam capability to perform precise cutting, there are some other cutting parameters that need to be finely tuned and controlled in order to get high quality cutting process. Among other cutting parameters that affect the quality of cutting process are cutting speed, laser power, stand-off distance and workpiece thickness. Thus, choosing the optimal cutting parameters that would produce the best cutting output is the main challenge.

For example, one of the quality aspects of the cutting process is surface roughness. Currently, machine operators use ñtrial and errorò approach to set-up laser cutting parameters in order to achieve the desired surface roughness. The setting up of laser cutting parameters is repetitive due to trial and error process. Obviously, this method is not efficient because it is very time and cost consuming. In addition, the method is also not systematic and depends on the experience of the machine operators. Furthermore, machining parameters are different between different workpiece materials and the type of laser beam used. Some companies have a system to record those machine conditions and parameters for each material and types of laser beam. But, since there are other parameters such as the cutting speed, laser power and stand-off distance, those recorded parameters are not adequate.

According to Zhang *et al.* (2007), there is no analytical method (theoretical) to determine the best and optimal machine parameters and conditions for laser cutting process. Researchers (Pan *et al.*, 2007, Zhang *et al.*, 2007, and Singh *et al.*, 2004)

Your complimentary use period has ended. Thank you for using PDF Complete.

Click Here to upgrade to Unlimited Pages and Expanded Features

to determine the parameters that influence the quality of the cutting parts.

Practically, optimization approach is a better approach in determining optimum machine parameters and conditions for laser cutting process compared to ñtrial and errorò approach. Recently, Pan *et al.* (2007) used Grey-Taguchi method to design the experiment and calculating the optimum machine parameters for laser cutting process. However, the Grey-Taguchi method can still be improved especially in its weight assignment in order to obtain optimum machine parameters.

This research investigates the effectiveness of **Variable Weight** Grey-Taguchi algorithm in achieving optimum set of Carbon Dioxide (CO_2) laser cutting parameters on acrylic sheet.

1.3 RESEARCH OBJECTIVES

There are two objectives of this research. The objectives are:

1. to determine the effect of weight assignment in Grey-Taguchi algorithm on the selected laser cutting parameters in optimization calculation.

2. to verify that the proposed Variable Weight Grey-Taguchi algorithm will generate better cutting parameter optimization than the existing Grey-Taguchi algorithm through Matlab assisted physical experiments of the laser cutting process on acrylic sheet.

1.4 RESEARCH SCOPE

In order to achieve the research objectives, two research scopes have been identified:

a) Although there are several factors contributed to the performance of laser beam cutting such as power requirement, types of shielding gases, cutting speed and feed rate, type of workpiece materials as well as beam intensity, this research concentrates on four factors. Factors considered are cutting

PDF Complete
Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

stand-off distance and surrounding temperature. These factors are chosen because the limitation of machine that used in this study.

b) This research is experimentally applied on acrylic sheet laser beam cutting process.

1.5 RESEARCH METHODOLOGY

This research is carried out through three main stages, which are:
First, literature reviews on fundamentals of Laser Beam Cutting (LBC) Taguchi method and Grey-Taguchi algorithms are conducted. This review is to know the principles of laser cutting process, the parameters that influence the quality of laser cut and the principles of existing Grey-Taguchi algorithms as well as their limitations.

Second, a new method is proposed in order to obtain the optimum cutting parameters. The proposed method, which is based on the Variable Weight assignment, is applied to overcome the limitation of existing Grey-Taguchi algorithm.

Lastly, experiments applying Grey-Taguchi algorithm (Pan *et al.*, 2007) and the proposed Variable Weight Grey-Taguchi algorithm on CO_2 laser beam cutting for acrylic sheet were conducted. Design of Experiment (DOE) by Taguchi method was used in designing the experiments. Control and noise factors are considered in the experiments as suggested by previous research. Finally, experiments are conducted to verify the performances of the proposed new method.

Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

ATION

This thesis is organized as follows:

Chapter 2: Overview of Laser Beam Cutting

This chapter describes laser properties and applications, laser beam cutting (LBC) principle and cutting parameters that influence the cutting quality.

Chapter 3: Development of Variable Weight Grey-Taguchi method

This chapter presents detailed discussion of current optimization methods that are applied on laser beam cutting process. In particular, three methods are discussed which are Taguchi method, Grey Relational Analysis (GRA) method and Grey-Taguchi method. Lastly, the modified Grey-Taguchi method called Variable Weight Grey-Taguchi method is presented.

Chapter 4: Physical Experiments of Parameter Optimization

This chapter presents the objectives of experiments, Design of Experiment (DOE), experimental setup, experimental results and analysis of the two optimization methods based on CO_2 Laser Beam Cutting of acrylic sheet.

Lastly in **Chapter 5: Research Conclusion**

This chapter concludes the research and recommendations for future works.

Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

CHAPTER 2

OVERVIEW OF THE LASER BEAM CUTTING AND OPTIMIZATION METHODS

2.1 INTRODUCTION

In the previous chapter, the overview of this research is discussed which contains research motivation, research objectives, research problem statement, research scope and research methodology. Lastly, thesis organization is presented.

In this chapter, detailed discussion about laser beam cutting (LBC) especially CO_2 laser are presented. This chapter starts with the fundamental of laser system and the principles of the laser beam cutting. It follows by laser applications in industry. Then, factors that influence the quality of cut in laser beam cutting will also be exposed.

2.2 LASER BACKGROUND

Laser is the acronym of Light Amplification by Stimulated Emission of Radiation. In 1917, Einstein had introduced stimulated emission, the concept of laser operation in one of his three papers on the quantum theory of radiation (Nahendra and Harimkar, 2008). The worldɽs first laser was demonstrated by Maiman using a ruby crystal in 1960 (The New Websterɽs International Encyclopedia 2007).

Laser is different from other conventional sources of light, such as sunlight and lamp. It has special properties, which differentiate it from other lights. The first property is

Your complimentary use period has ended. Thank you for using PDF Complete.

Click Here to upgrade to Unlimited Pages and Expanded Features

...s that laser only produces one colour of light while the other sources of light such as sunlight produces seven colours of light (Ion, 2005). This is an important feature because one colour of light means single wavelength. Wavelength of laser light relates to the power of the beam.

The second special property of laser light is that it travels in an orderly phase relationship, referred to as coherent (Brown, 1998). It is coherent because during the stimulated emission process, the emitted photon has same frequency and phase with the bombarding photon. As the stimulated emission continues, both of these photons bombard the other excited atoms in active medium and continuously produce photons that have the exactly same frequency and phase. So, laser light consist of all photons that have same frequency and phase. Thus, a coherent light is produced.

Coherent light have higher intensity compared to incoherent light such as lamp and sunlight. It causes laser light waves which have sinus shape lined up with each other. The result is each peak and valley of laser wave has a same point with the other waves. While for the other source of light, waves are incoherent because waves are not lined up. This phenomenon may cause peak and valley for two different waves have a same point as shown in Figure 2.1 on the next page. Thus, the peak may eliminate the valley for other waves that causes these source of light has low intensity. So, coherent light have higher intensity compared to incoherent light such as lamp and sunlight.

Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

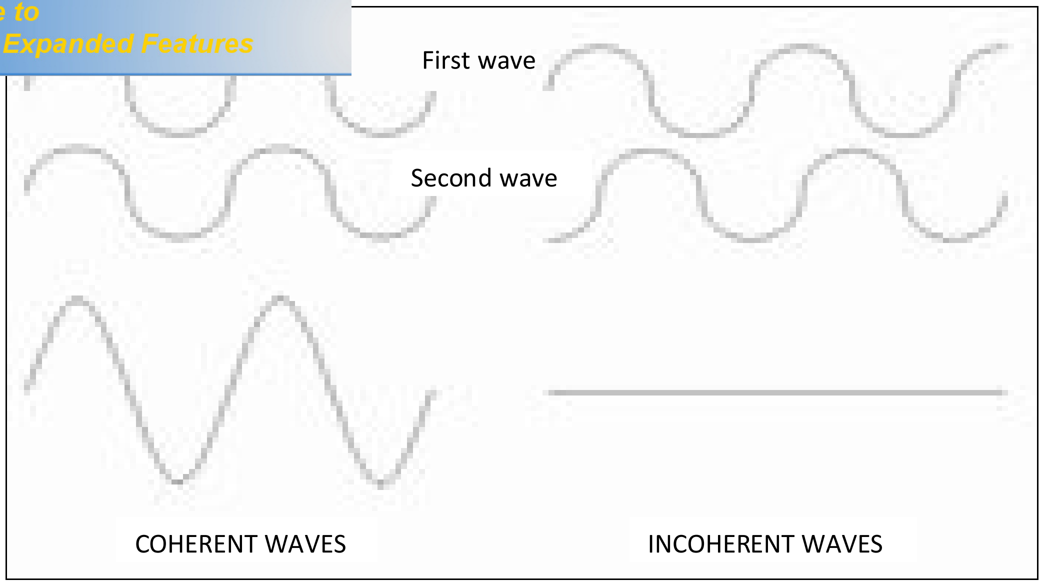

Figure 2.1 Coherent and incoherent waves

Laser is also a nearly collimated light; it does not significantly diverge or converge. This property becomes an advantage for laser because the beam can be focused on a very small spot which is useful in laser applications. As a result, heat from the beam can be delivered to the workpiece in a very high intensity.

2.3 LASER GENERATION PROCESS

There are three stages to produce laser beam which are population inversion, stimulated emission and amplification.

Population Inversion Stage

Population inversion is a process of inverting the population of electrons in the energy levels of an atom (Ion, 2005). At equilibrium, most electrons are at the lower energy levels. Similarly, there are fewer electrons at the higher energy level. Population inversion is a process to reverse i.e. to cause population of electrons at higher energy level to be higher than at the lower energy level.

PDF Complete
Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

a total of 11 electrons. At equilibrium, the lowest energy level has two electrons, the second energy level has eight electrons and the outer most, the third energy level has only one electron. Population inversion on this atom is to reverse this condition that is to cause the electrons from the second energy level to jump to the third energy level.

According to Boltzmann law, the higher energy states are the least populated and the population of electrons in the higher energy states decreases exponentially with energy as Equation 2.1 below (Ion, 2005):

$$\frac{N_2}{N_1} = e^{-\frac{(E_2 - E_1)}{kT}} \qquad \text{Equation 2.1}$$

In Equation 2.1, E_2 is the higher energy level, E_1 is the lower energy level, N_2 is the population of electron at higher energy level, N_1 is population of electron at the lower energy level, k is Boltzmannôs constant (1.381 x 10^{-23} JK^{-1}) and T is the absolute temperature.

In order to create an efficient population inversion, it is a must for the atoms to possess a large group of upper absorption energy level. So, energy can be absorbed over an appreciable frequency range. In order to maintain a population inversion, the rate of population of upper state must be higher than the lower state. So, laser beam can be produced steadily.

This process may be achieved by using a variety of sources to excite the atoms. Optical, electrical and chemical means are the most common in industrial laser (Ion, 2005). In optical pumping, flash lamp is used to excite atoms. In electrical pumping, electric current is used to produce electron beams that pump free electrons to excite laser medium. Electrons from electric current transfer their energy to the laser source.

Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

...es flash lamp as its pumping source. Atoms in the active medium are excited by flash lamp that emits bright and intense light. These lights emit steady electric charges and are absorbed by the active medium corresponding to its wavelength. The flash lamp is placed parallel to the active medium to produce more population inversion. This is because light emitted from the flash lamp goes through the cross section of active medium.

Stimulated Emission

The second process of laser generation is stimulated emission. Stimulated emission is a process of external photon bombarding electrons at the higher energy level of an excited atom (Ion, 2005). Electrons at higher energy level are stimulated as they fall back to the lower energy level emitting photon of the same frequency, phase and direction with the bombarding external photon. This is the process that produces the unique coherent property of the laser.

Referring to Figure 2.2 on the following page, the stimulated emission process is the process that changes the energy level E_3 to E_2 then to E_1. The drops to the lower energy level cause the generation of laser light. Once the electrons are in the lower energy level, they are pumped to the higher energy level by the population inversion process. This process is repeated so that constant laser source is generated.

PDF Complete
Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

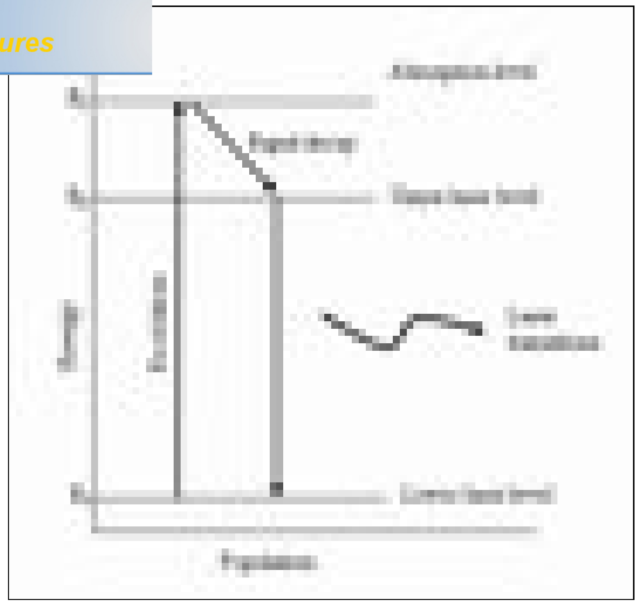

Figure 2.2 Population inversions (Ion, 2005)

The drop of electrons from the higher energy level to the lower energy level is due to the instability of the electrons at the higher level. For example, the number of stable electrons for Natrium at the highest energy level is supposed to be only one electron. After the population inversion, the number of electrons at the highest energy level is more than one. This is not the stable state. Therefore, the excess electrons drop to the lower energy level and this releases the laser light.

The bombarding photons and the emitted photons may then strike other excited atoms, stimulating further emission of photons, all of the same frequency, phase and direction. This process continues to produces a sudden burst of coherent radiation as all excited atoms are discharged in a rapid chain reaction (Hetch, 2008).

The emitted photon will have frequency *v* (nm) and energy *hv* (J), given by the following equation.

$$E_2 - E_1 = hv \qquad \text{Equation 2.2}$$

In Equation 2.2, *h* is Planckôs constant (6.626068 x 10-34 m^2kg/s).

Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

The third stage of laser generation is amplification process. It is a process of increasing the laser light strength (Hetch, 2008). The laser light strength is amplified by generating more photons that have the same wavelength. The same wavelength will ensure the laser beam is coherent.

Amplification occurs in a resonant cavity or optical cavity consisting of a set of well-aligned highly reflecting mirrors at the end, perpendicular to the cavity axis. This is shown in Figure 2.3. The active laser is placed in between the mirrors with one of the mirrors is a fully reflecting mirror, almost 100% reflectivity and the other is partially reflecting mirrors.

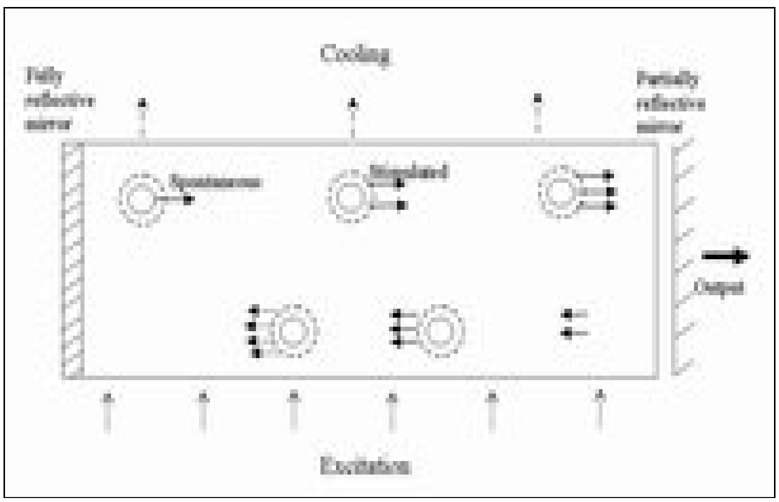

Fig. 2.3 Schematic illustration of amplification (Ion, 2005)

The fully reflective mirror is used to reflect the photons so that it remains at the same frequency and to help create chain reaction by bombarding other excited atoms. The function of the partially reflecting mirror is to allow some of the photons in the cavity to emerge as laser output (Charles, 1999).

The amplification factor *A*, which measures the increase in power is given by Equation 2.3 below.

Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

Equation 2.3

where L is length of laser medium and G is gain per unit length. From the Equation 2.3, the longer cavity size (L), the more amplification is achieved.

In summary, laser generation process consists of three stages, which are population inversion, stimulated emission and amplifications. Population inversion is a process to invert the population of electron in atoms of active medium. This inverted population of electrons then goes through stimulated emission which uses a bombarding photon to collide with the atom. Then, the photon will be emitted with same frequency and phase with the bombarding photon. This process continues to the amplification stage.

In the next sections, several types of lasers used in industries will be presented in particular the materials used in the construction of laser source, the advantages and disadvantages of different types of laser.

2.4 TYPES OF INDUSTRIAL LASERS

Industrial lasers are normally classified by the active lasing medium material. An active lasing medium is the material that is used to produce laser light. In other words, the atoms of the active lasing medium materials go through the population inversion, stimulated emission and amplification process.

Based on the active lasing medium materials, the industrial laser can be classified into four types: solid-state, semiconductor, liquid and gas lasers.

PDF Complete
Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

Solid-state laser is a type of laser that is produced by atoms of solid active lasing medium embedded in the host (Barat, 2006). The term solid-state indicates that the active lasing medium material is a solid, instead of liquid or gas.

There are two main components of solid-state laser; host and active medium. Host is the material that is embedded with active medium. Suitable hosts are crystalline materials that require high thermal conductivity for thermal stability to accommodate the heat generated during the laser generation process. Host also must have low thermal expansion coefficient because as it heats the expansion of the inner side of host is higher than the outer side of the host. These unequal expansions will cause crack in the structure of the host (Barat, 2006). The material of host is also important as it determines the energy level characteristics in producing laser (Nahendra and Sandip, 2008). Examples of common host are crystals, glasses or other transparent solid materials.

Active medium is a small percentage of impurity ions doped in the host. One of the active medium used in solid-state laser generation is yttrium garnet (YAG) that doped in neodymium (Nd) host, called Nd:YAG laser (Hitz, 2001). These dopant ions go through the population inversion, stimulated emission and amplification processes in generating the laser beam. Other than Nd:YAG, there are several types of solid-state lasers implemented in industry, such as Ruby laser, Nd:glass laser and Ti-sapphire laser.

Ruby, neodymium and titanium (Ti) are suitable active medium because these materials contain atoms or molecules that can be excited in order to produce laser beam. For example, ruby is a suitable active medium because it contains chromium atoms, which can be excited during population inversion process.

Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

Semiconductor laser is a type of laser that uses semiconductor as its lasing medium. Semiconductor material is a type of material that has n-type material combine with p-type material. Sometimes, semiconductor lasers are also called diode lasers or laser diodes (Barat, 2006 and Noriah, 2002).

Laser beam generated in semiconductor laser is by pumping electrical current to junction region, where n-doped and p-doped semiconductor materials meet. Free electrons from n-doped move across the junction and combines with hole in p-doped, and vice versa. The movement of electron cause energy loss and emit an electron (Hitz, 2001).

Semiconductor lasers are different from solid-state lasers because of it is based on radioactive recombination of charge carries. The problem occurs when electron moves, it produces heat. Since very high current flow is needed to maintain a population inversion, heat generated can destroy other devices. In order to reduce heat generated while maintaining population inversion, modern design of semiconductor lasers packs the junction into a small region; where the stimulated emission occur. The density of stimulated emission is increased by increasing the density of electrons and holes (Barat, 2006).

Common materials for semiconductor lasers are: gallium arsenide (GaAs), aluminium gallium arsenide (AlGaAs), gallium phosphide (GaP) and indium gallium phosphide (InGaP) (Hitz, 2001).

Liquid Laser

Liquid laser is a laser type that uses liquid solutions as lasing medium. Most of the solutions are fluorescent organic dyes dissolved in suitable liquid solvent. These lasers are optically pumped, usually by another laser because it requires high energy source of light to produce acceptable number of population inversion. Light from the

Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

the dye molecules, which then re-emits the absorbed energy. Some of the available liquid lasers are: Rhodamine 6G laser, Coumarin 102 laser, Stilbene laser (Hetch, 2008).

Gas Laser

Gas laser is a type of laser that uses gas as the active lasing medium. Most gas lasers share similar features as shown in Figure 2.4 (Hetch, 2008).

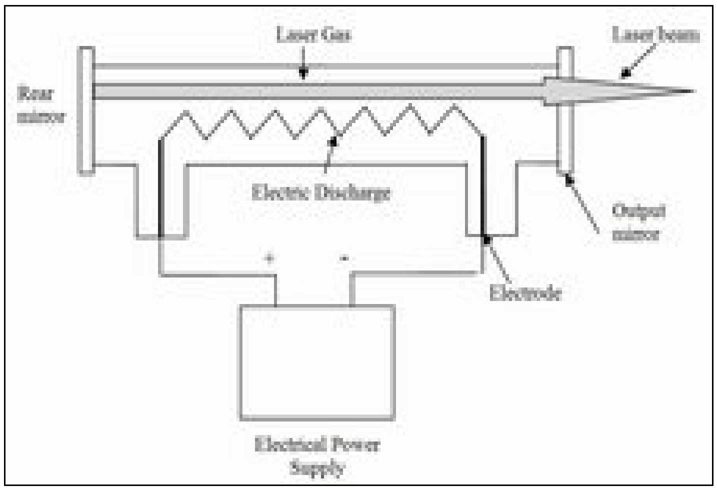

Fig. 2.4 Generic gas laser (Hetch J., 2008)

The gas laser is contained in a cylindrical tube with rear and output mirror at each end. The rear mirror totally reflecting while the output mirror allows some photons to go through to emit light as laser beam. An electric discharge passing in cylindrical laser tube to excites atoms. These photons bounce back and forth on the two mirrors at each end of the tube. Some photons may go through output mirror and emitted as laser beam. There are several types of gas lasers available, such as: Carbon dioxide (CO_2) laser, Argon laser. Krypton laser, Copper vapor laser and Gold vapour laser.

PDF Complete
Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

LASER TYPES

Laser types can be compared based on their properties such as the excitation method, the performance of population inversion, the wavelength generated, the power generated and the relative size and cost. Table 2.1 summarizes the comparison between the four types of laser.

Table 2.1 Comparison between laser types (Hetch, 2008)

Properties	Solid-state laser	Semiconductor laser	Liquid laser	Gas laser
Excitation method	Optical/ electrical	Electrical	Chemical	Electrical
The performance of population inversion	High	High	Medium	Low
The wavelength generated	280 nm ï 3.3 µm	850 nm ï 20 µm	390 nm ï 640 nm	193 nm ï 10.6 µm
Size and cost	Small	Small	Medium	Large

Each type of laser requires different pumping or excitation methods. For gas laser, energy that excite gas atoms comes from electric current that transfer their electron energy by passing through the laser material. Same goes to semiconductor laser, it uses electrical pumping method. In contrast, liquid laser uses chemical reaction by the liquid lasing medium to excite the atoms (Noriah, 2002). While for solid-state laser, optical or electrical pumping method is used.

The suitability of excitation or pumping method is merely depending on the lasing medium of the laser. For example, atoms in gas as lasing medium for gas laser can easily excite by pumping energy to collide with them. The nature of gas, atoms can moves freely in random movement. Thus, electrical pumping method is the most

PDF Complete
Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

cal pumping method is not suitable as there is no any chemical reaction involves.

Population inversion in gas laser is less than solid-state laser. It can be explained by the physical nature of gas. The density of gas is less than the density of solid in solid-state laser. So, a large volume of gas is needed to achieve the significant number of population inversion. This can explain why the size of gas laser is much bigger than the solid-state laser. However, the cooling system in gas laser is simpler than solid-state laser because the thermal conduction of gas is higher than solid materials.

Since the nature of liquid is it has more density than gas, population inversion and stimulated emission in liquid solution is higher than gas. So, the beam only needs to make few passes through the liquid and not much amplification needed. This can explain why the size of liquid laser is much smaller that gas laser. However, this scenario leads to high losses, as any reflection of photons on reflective mirror and liquid cavity will reduce energy. In order to overcome this problem, pumping cavity are often coated or anodized that will absorb the lasing wavelength but effectively reflect the photons.

Short wavelength laser generates low electron energy. It leads to thermal reaction. By contrast, long wavelength laser generates higher electron energy, which leads to photochemical reaction (Hetch J, 2008 and Hitz 2001).

Compared to solid-state and gas laser, liquid laser can produce wider range of wavelengths. So, this type of laser usually includes a wavelength selection device. Hence, wavelength of laser can be selected or tuneable. Wavelength tuning produces a different wavelength of the laser light. The wavelengths can be tuned within the full range of wavelengths produced by the fluorescent dye. The liquid or dye solution also can be replaced by another type with the same laser, if other wavelengths are required.

PDF Complete
Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

is selected to be used in this study. It is a molecular gas laser. This type of laser contains 9.5% of carbon dioxide (CO_2) that acts as primary lasing medium. It also contains 13.5% of nitrogen (N_2) gas that help to excite CO_2 atoms and 77% of helium (He) acts as a buffer heat to heat transfer.

Carbon dioxide laser is highly efficient, which is up to 20% of the input power can be converted into laser beam (Hetch, 2008 and Hitz, 2001). It is one of the most important and widely applied lasers in the laser machining of materials (Nahendra and Sandip, 2008). In addition, flowing Helium gas that acts as a buffer heat removes the heat generated from laser generation process efficiently.

The principle of CO_2 laser is electron collisions raise CO_2 molecules to higher energy level. Stimulated emission occurs when these molecules drop to two laser transitions level. During this process, they emit energy as photon. If it drops to first low energy level, it releases photon with a wavelength of 10.6 µm which is the strongest and most common lasing. The lasing wavelength can also be at 9.6 µm if the excited CO_2 molecules drops to the second low energy level and it can be vary between 9 to 11µm (Hitz, 2001).

However, a large volume of gas is required to achieve enough population inversion to produce laser (Nahendra and Sandip, 2008, Meschede, 2004). It is because physical nature of gases is they have low density. So, size of equipment of gas lasers usually bigger than solid-state lasers. Laser emission from gases is well defined, and occurs in three discrete parts of the electromagnetic spectrum; ultraviolet, visible and infrared.

This type of laser offer some advantages over solid materials. Some of these advantages are:

- Gases are relatively inexpensive.
- Gases can be easily transported for cooling and replenishment.
- Gases act as homogeneous lasing medium.
- Gases can be excited directly with an electric current.

Your complimentary use period has ended. Thank you for using PDF Complete.

Click Here to upgrade to Unlimited Pages and Expanded Features

cussed the types of lasers used in industries as well as their advantages and disadvantages in specific situation. In the next section, we will discuss the specific laser applications in manufacturing.

2.6 LASER APPLICATIONS IN MANUFACTURING

The applications of lasers have been demonstrated in casting, forming, joining, cutting, surface hardening, and many other machining processes. Lasers are widely used in industry as cutting tools due to its flexibility of the cutting conditions, obtaining high quality end product, quick set up and non-mechanical contact between the work piece and the tool (Avanish *et al.*, 2008, 2007).

The utilization of laser in manufacturing is continuously spreading in many applications especially in laser beam machining (Ion, 2005). The special property of laser, especially the collimated property, is utilized in many manufacturing applications. It means that laser beam can be focused on a very small spot. Hence, very localized and precise machining process can be done. On top of that, the heat generated by the laser beam is very high. This heat will be absorbed by the workpiece at a very high intensity. During the laser machining process, temperature of workpiece will increase from room temperature to the operating temperature. Ion (2005) states that working temperature for laser machining processes is between 1300°C to 1600°C. The generated heat from the laser beam is used effectively in laser machining process.

In the next discussions, four specific laser applications on material processing are presented. The applications are laser welding, laser drilling, laser heat treatment process and laser cutting processes.

PDF Complete
Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to
Unlimited Pages and Expanded Features

Laser welding is a fusion welding process whereby the heat carried by the laser beam is focused on the joint to be welded (Schrader and Elshennawy, 2000). This process is a non-contact approach in material joining.

The process begins with focusing the laser beam on the materials. When the beam is irradiated on the surface of the workpiece, the heat energy carries by the laser beam will be absorbed by the workpiece. It causes heating, melting, and/or evaporation of the workpiece. Then, a pool of molten material which is called óweld poolô is created on the surface of the workpiece.

The process continues as the laser beam continuously heating the workpiece through the thickness of the material and produces a keyhole, as shown by Figure 2.5 below. Within the keyhole, laser energy is reflected repeatedly at the walls of keyhole. So, the keyhole plays an important role in this process, by transferring and transmitting thermal energy deep into the material.

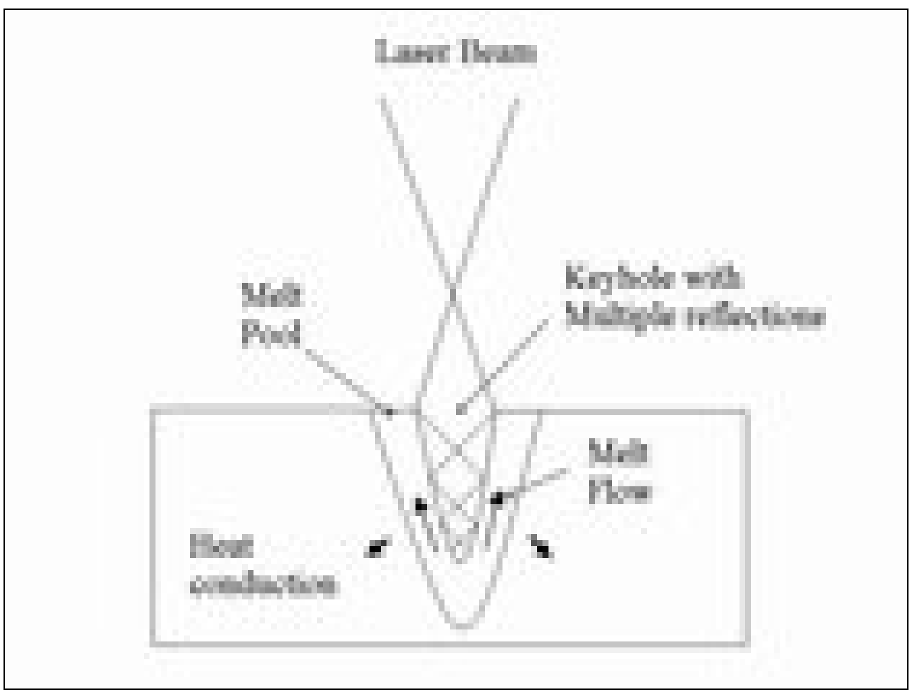

Figure 2.5 Laser welding (Barat, 2005)

PDF Complete
Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

o perform a variety of joints such as lap weld, butt weld, T-weld, fillet weld and edge weld. There are two methods of laser welding, which are continuous seam or spot welding methods. Continuous seam welding is a process that uses continuous laser beam from start to finish. This method is suitable for thicker materials. The second method is spot welding which usually applied on thinner materials with lower melting point.

This process can be applied for wide range of materials like metallic materials, ceramics, polymers and composites. This is the main advantage of laser welding compared to conventional welding process. However, these materials cannot be weld with equal ease, due to different thermo physical properties (Nahendra and Sandip, 2008). In addition, aluminium and copper and their alloys are also difficult to weld by laser because they are good reflector. In fact, copper is used as reflective mirror in some laser like Carbon Dioxide (CO_2) laser.

Compared to conventional welding process, laser welding is relatively cheap. Even though the setup cost is higher, maintenance cost for this process is lower. It is because laser welding process does not require any welding fill. In addition, welding speed for this operation is faster than conventional welding because of automation and fast heat transfer (Ion, 2005).

Laser Drilling

The second laser application in manufacturing is laser drilling. Laser drilling is a process to create through hole by removing material through laser beam and material interaction (Walker, 1996). Thus, it is a non-contact process. In fact, the first laser was a ruby laser which was introduced to drill diamond.

During the drilling process, high intensity of laser beam is focused onto the surface of a workpiece. The surface will be heated, melted and vaporized due to thermal energy from the laser beam as shown in Figure 2.6 on the next page. Vapour will build up pressure that causes a flow flush of vaporized and molten materials. Then, a

Your complimentary use period has ended. Thank you for using PDF Complete.
Click Here to upgrade to Unlimited Pages and Expanded Features

surface of workpiece which is called ócraterô (Ion, 2005 and Brown, 1998).

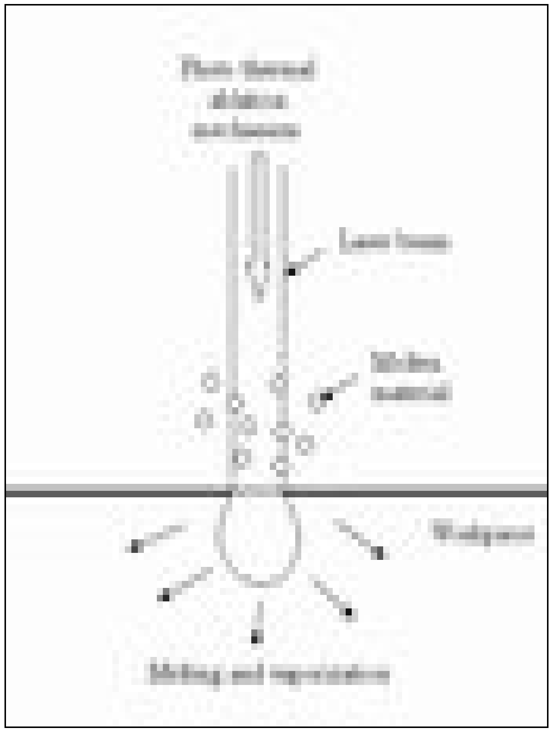

Figure 2.6 Laser drilling (Ion, 2005)

Ion (2005) had listed are some advantages of laser drilling compared to mechanical drilling process such as:

- High throughput lead to low-cost processing. Laser drilling is faster than mechanical drilling. More outputs lead to lower cost especially cost of machine operator.
- Noncontact and no tool wear. Laser welding use laser beam as cutting tool while mechanical drilling use drill bit. Drill bit will wear because of contact and excessive use.
- Applicable to wide range of material including hard-to-drill materials such as ceramics and composites. This is the limitation of mechanical drilling process. Different materials require different type of drill bits and ceramics and composites cannot be drilled by mechanical drilling process.