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Reviews on Laser Cutting Technology for Industrial Applications

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ABSTRACT

In this paper, an overview of the laser technology applied for the industrial has been reviewed. In general, this technology was used in several engineering applications such as industrial, medical, science, research sectors, etc. Focusing on the laser technology in the industrial section, it was, normally, employed for many purposes i.e. target marking, welding, drilling, and also cutting. Consequently, the laser cutting technology was, however, divided into three classifications YAG, CO_2, and fiber laser, respectively. Each laser types have different advantages and disadvantages depending on the material type. The advantages by using laser cutting compared with the general cutting machines were exploited in terms of narrow kerf, high cutting speed, low heat-affected zone (HAZ), improve efficiency of the cutting process, high accuracy, etc. However, the main objectives from the technology used were increasing of the products and also decreasing the production cost. In the opposite way, some disadvantages of the technology were summarized by complexity to operate, high maintenance cost, and also high power consumption. In Thailand industry, there were many factories used this technology as a cutting process. Unfortunately, only few researches were published. It might explains that this technology were difficulty to develop, high investment, and also easy to import from aboard. For becoming to the Thailand 4.0 community, the Thailand industry might awareness to reduce the importing machine and boosting some policies to create novel innovative / know-how from the own country.

Keywords: Industrial lasers, laser cutting machine, laser technology, Thailand 4.0

1. INTRODUCTION

Laser technology or the other words called as "*laser*" is the purest light that scientists produce. The laser word is a synonym of *"light amplification by simulated emission radiation"* [1-2]. It is increasing the amount of light waves by stimulating the release of the light. Laser energy has many characteristics depending on the purpose of the design. Currently, laser applications are widely applied in several fields such as medical, medicine, surgery, ophthalmologist and dental, etc [3-4]. In addition, it's also used for homeostatic hemorrhage and cancer treatment [4]. Some lasers typical are employed in medical applications including to the carbon dioxide laser (CO_2), argon laser (Ar), etc. According to the telecommunications field, the laser is, normally used as a transmitter through the optical fibers to transmit the designed signals into equipment, telephones and computer [5]. Some advantages of the laser usage in telecommunication are presented in terms of no noise, and more stable for the communication. Laser diode is a type of the laser technology which has, widely, been applied in the offices and residential homes, such as laser pointer, laser printer, remote control television, audio, and video. In various exhibitions, the laser is operated for advertising, theater, concerts. Moreover it has been used in the metrological measurement as a standard for conveying accuracy in the dimensional measurement systems and calibration the instruments. In the industrial sector, the laser technology is, generally, used for drilling, cutting and welding of various materials, which the penetration patterns are small and very sharp [6]. Therefore, it has ability to work in the highest resolution. Focusing on the applications of the laser for industry, it has been applied into 3 main classifications; cutting, welding, and drilling respectively. For the first type, it is using for scratching or cutting the material under the computer numerical control (CNC) [7]. However, it is also divided into two sub-main types, moving parts and flying optics respectively. For the first part, it is a way to move the work piece onto the desired direction for marking and cutting. This method has ability to mark or cut with high resolution materials. The latter part is, consequently, an alignment of the laser to move in the right direction. It is usually used in the large work areas and high power lasers. However, the advantages by using lasers marking and cutting are no accumulation of heat in the material which the material does not twist after cutting, high accurate and precise, no interference signal, etc. The laser welding is using the laser beam to melt the two materials into a homogeneous. Its advantages are exploited in terms of very small

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welding points, shallow and narrow welds [8]. For the drilling laser, it's, widely, operated for drilling holes that are very small or used in the high hardness materials such as ceramics, diamonds etc. [9].

In this paper, we describes about the usage of the laser cutting for the industry. Moreover, we are investigating the characteristic of such laser, cutting capacity of each laser machine, and also type of laser cutting. Furthermore, we are summarizing some advantages and disadvantages of such laser for applying in the industry, especially for Thailand industry.

2. OVERVIEWS OF LASER CUTTING TECHNOLOGY

Most of the lasers used in the manufacturing industry are employed for cutting in common materials, such as steel, aluminum, stainless, thermoplastics, and other work pieces [10]. Laser beam cutting (LBC) is a process of cutting by heat, which melts the material and becomes vaporized by the laser heat; the process uses gas to remove the molten metal [11-12].

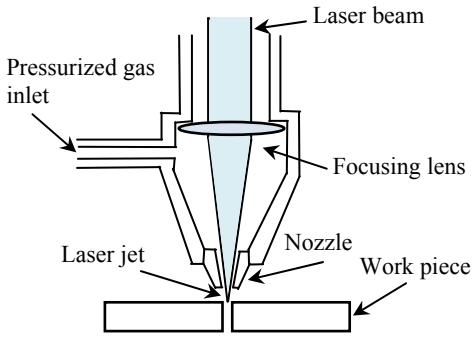

Figure 1 Principle of laser beam cutting (LBC)

Figure 1 illustrates a basic of the lasers cutting, which consisted of operating the main component such as laser beam, focusing lens, pressurized gas inlet, laser jet and nozzle, etc [13]. Inside of the laser cutting, the gas will be sprayed from the nozzle that is aligned with the laser or the lateral angle to the laser beam. There are two types of gases used in the cutting process; active gas and inert gas respectively. The examples the active gas can be presented in terms of nitrogen or air, while the inert gases are helium or argon, depending on the type of cutting material and the quality of the cut. It can control the environment around the cutting area, the gas which came out from the nozzle blow can away those of small parts from the melting objects. This makes the cuttings area smooth and clear. The gas usage in the laser is oxygen therefore; the temperature could be raised higher from the oxidation effect. As a result, the speed and efficiency of the cutting processes are improved. There are two laser beams projection; pulsed projection and continuous wave (CW) projection. Moreover, there are a number of laser beams which can thus be different in the wavelength, as shown in table 1 [14].

Table 1 Wavelength of laser types

Type of lasers	Wavelength
4^{th} Harmonic of Nd: YAG	266 nm
3^{rd} Harmonic of Nd: YAG	355 nm
2^{nd} Harmonic of Nd: YAG	532 nm
Nd: YAG	1,064 nm
Fiber laser	1,074 nm
CO_2	10,600 nm

The advantages of laser cutting are high cutting speed, narrow cut, low heat, low torque, low vibration and low gas etc. However, some disadvantages of the laser cutting process are exploited in terms of heat, the proximity of the cutting edge, the heat radiated from the cut area and electrical properties of the work piece. The impact of HAZ is considered in the material cutting process [1]. However, the most common types of industrial laser cutting systems are including by:

2.1 YAG Laser

Solid state lasers are constructed by doping a rare earth element or metallic element into a variety of host materials. The most common host materials are Y_3, A_{15}, O_{12} and amorphous glass. The laser rod used in laser cutting is a synthetic crystal of "Yttrium Aluminum Garnet (YAG)". The YAG material is the host material that contains a small fraction of neodymium, the active element. The YAG crystal is an ideal host for the lasing material Nd^{3+}, being physically hard, stable, optically isotropic, and has good thermal conductivity that permit laser operation at high average power levels. Neodymium YAG is an excellent lasing material as it produces the highest level of powers than any other doping element. The Nd: YAG laser is discussed due to it is the most common solid state laser that used in the industry.

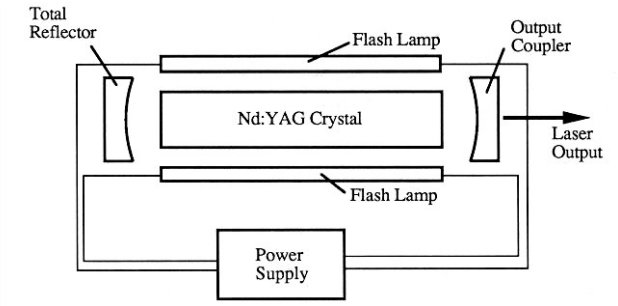

Figure 2 Structure of YAG laser system

Figure 2 shows the structure of YAG laser system. In general, the Nd: YAG is a solid state laser. This means that the medium is a solid crystal and it uses light energy as the pump source. Typical solid state lasers are pumped optically by the arc lamps or flash lamps. The arc lamps typically are used for continuous wave (CW) pumping. However, the flash lamps are operated with the pulsed lasers. Nowadays, the diode laser pumping is becoming increasingly popular and will be opened the doors to receive new industrial applications [8], [13], [15-16].

2.2 CO_2 Laser

A carbon dioxide laser is, generally, using a gas mixture of carbon dioxide (CO_2), nitrogen (N_2) and helium (He) with a standard ratio of 1:1:10. The CO_2 molecules constitute the active lasing medium, the N_2 gas serves in an energy transfer mechanism and the He atoms enhance the population inversion by depopulating the lower energy states. The population inversion and lasing transition in a CO_2 laser is established between vibrational and rotational energy states. Most CO_2 lasers are pumped by a high pressure electrical discharge.

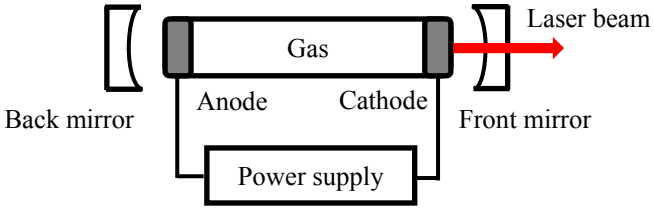

Figure 3 Fundamental of CO_2 laser system

Figure 3 shows a fundamental of CO_2 laser system. The laser is, normally, requiring a lasing medium, power supply and also a resonator cavity to sustain oscillation (back-front mirror). The lasing medium can, thus be obtained a CO_2 glass tube system. The power supply would be excited atoms or molecules of the lasing medium to an upper energy state by using electronic means or kinetic energy transfer. Laser transmission is initiated by spontaneous emission and amplified by stimulating emission along the axis of the resonator cavity. The cavity mirrors have been reflected the photons back and front through the laser medium for increased amplification. Energy is introduced into the laser through the power supply, but only a fraction of the "wall plug" energy which is presented in the laser beam as it exits the front

aperture. A typical laser might be less than 10% of the efficiently. Moreover, most of the energy is also lost in the form of heat [17-18].

2.3 Fiber Laser

Fiber laser has been made huge advances in the recent years. Consequently, is not widely recognized in an industrial tool, but will be implemented in some applications such as cutting, welding, piercing and drilling etc. It could be enhanced by the development of more powerful lasers with high beam quality, efficiency and also stability. The structure of fiber lasers has been shown in figure 4.

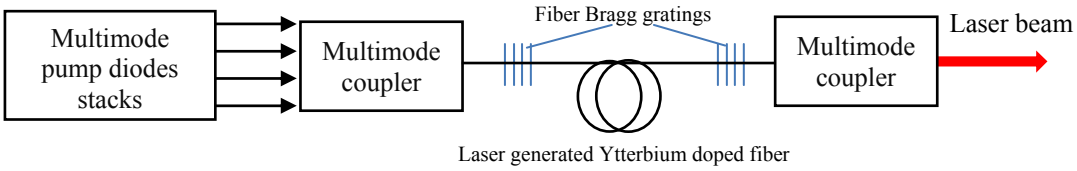

Figure 4 Principle of fiber laser system

Figure 4 illustrates the principles of fiber laser system. The high power of fiber laser system consists of a double cladding, Ytterbium doped fiber, and also groups of multimode high power laser diodes respectively. The groups of multimode pump diodes are coupled on the side of an active fiber. A coil of the active fiber with two Bragg gratings form the laser medium. The Bragg gratings would thus be reflected particular wavelength of laser and transmit to the others part of the system [8], [19-21].

The laser sources usage in the present estimation is including of Nd: YAG, CO_2 and Fiber lasers. They are, commonly, used in the industry for laser cutting applications. Table 2 is characterizing the comparison of difference laser types for applying to the industry [22-23].

Table 2 Comparison in difference laser types for applying in industry.

Characteristics \ Laser type	Nd: YAG	CO_2	Fiber Laser
Lasing medium	Crystalline rode	Gas mixture	Doped fiber
Wavelength (nm)	1,064	10,600	1,070
Beam transmission	Fiber, lens	Mirror lens	Fiber, lens
Typical delivery fiber Ø (mm)	0.6	-	0.1-0.2
Output power (kW)	Up to4	Up to 15	Up to 20
Typical beam quality (mm, mrd)	25	3.7	20
	12	3.7	1.8
Maintenance interval (1,000 hours)	0.8-1.0	2	100
Power efficiency (%)	3-5	5-8	20-30
Approximate cost per kw (KS)	130-150	60	130-150
Foot print of the laser source	Medium	Large	Small
Laser mobility	Low	Low	High
kW laser cost (€/kW)	260	60	160

3. LASER CUTTING FOR INDUSTRIAL APPLICATIONS

Nowadays, the laser technology is beginning to play a greater role in the industrial sector. This is due to the accuracy of the laser over other technologies. The laser cutting materials will result in less site effect, resulting in quality products. Therefore, the industry is turning to lasers in the manufacturing process. Materials used for laser classification can vary depending on the type of laser as shown in the following:

3.1 Laser cutting steels

Most of thickness metal materials, such as metal plates or reinforced metal plates are, usually, cut by using the CO_2 laser. It causes to the CO_2 laser has higher energy level than the others. Normally, the thicker metal plates need higher energy for the cutting process. According to the best of cutting process, we need to focus on the ratio between the thickness and the strength of the material. The benefit of laser cutting can thus be created very small welds, even thinner than the thickness of the material. The smallest could be one-fifth thinner than the material. For Nd: YAG laser, the cutting material has to be thinner than twenty millimeter. However, the oxygen gas can be used to improve the cutting efficiency and allows thicker material cutting. In this case, the laser has been used to raise material's temperature. Consequently, the oxygen gas is accelerated exothermic reaction in order to improve cutting efficiency. In terms of fiber laser, there is a proof of 5 kW with 250 millimeter focus lens length with the thickness of 40 millimeters [24].

Figure 5 Fiber laser cutting machine and its output example

(Ref.: http://yueminglaser.sg/8-5-fiber-laser-cutting-machine-for-tubes-and-sheet-metal)

3.2 Laser cutting aluminum / Stainless steel

Carbon-aluminum and stainless steel are metals which are able to reflect the light and heated the conductor. This may sometimes affects to the quality of laser cutting procedures. The best solution is to increase the energy level and use pressurized the gas technology. However, the increasing of the energy level might be raised the budget on the connecting tool, such as gas filters which are needed to be replaced more frequently. In literatures, there are some researches experiments on parameters which is affected to the production quality, including kerf width, kerf deviation, kerf taper, heat affected zone (HAZ), dross formation and surface roughness. For examples, Leone *et al* was studied on a suitable parameter for the aluminum alloy 6061 T6 cutting with a power of 150 watt in the multimode pulsed laser machine [26]. Moreover, Tamizhmani *et al* was finding out the optimize parameters of 0.5-millimeter stainless steel for cutting with small heat affected zone [1]. Furthermore, Amit and Vinod was designed a model for explaining to the cutting procedures of aluminum alloy with thin sheet for straight and curved profile [11-12]. Consequently, Ambar *et al* was investigated the most fitted parameters range of 4 to 20 millimeter stainless steel for cutting in the dry air and underwater environment [27]. All of examples as mentioned above using only the Nd: YAG laser machine. Furthermore, Ahmet *et al* was used few mathematical models for surface roughness prediction and width of heat affected zone in order to cut 3 millimeter and 4 millimeter of the alloy steels by using CO_2 laser [6]. Finally, Rodrigues *et al* was finding out the best parameters for 2 kW of the laser diode for cutting an 1 millimeter stainless steel [28].

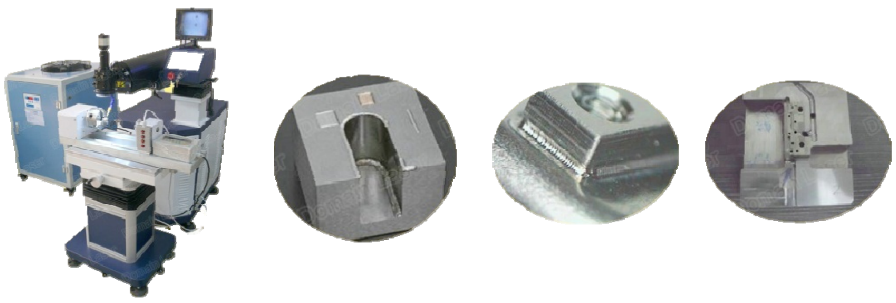

Figure 6 Nd: YAG laser machining and its output examples

(Ref: http://www.domainlaser.com)

3.3 Laser cutting the other material

Apart from steels, aluminum or stainless steels, laser cutting can be used on other materials including CO_2 laser cutting on thermoplastics (polymethylm - methacrylate, polycarbonate and polypropylene) with grey relational parameter analysis (GRA) [29]. Furthermore, Riveiro *et al* was studied in CO_2 laser for cutting with a parameter of 3 millimeter for the carbon fiber reinforced plastics (CFRPs) and also 10 millimeter for the natural granite without affecting kerf width, taper angle and width of the HAZ [30-31]. In addition, Bashir *et al* was investigated some experiments on Nd: YAG laser cutting for nonmetallic such as paper, plastic, wood, cloth, glass, and rubber [32].

Figure 7 CO_2 Laser cutting machine with some output from non-metal materials

(Ref: http://www.domainlaser.com)

4. APPLICATIONS OF LASER CUTTING IN THAILAND INDUSTRY

In Thailand, there are a few laser cutting were studied. For example, Nara was studied some experiments on the 4 millimeter stainless steel by using SUS304 laser and also employing ANOVA to analyze the power, frequency and also cutting speed with 3^3 factorials [33]. In addition, Rittichai *et al* was used 2^3 factorials on a power, pressure gas and cutting speed for cutting 6 millimeter stainless steel [34]. Further, Worawat *et al* was used the Nd: YAG laser machine with more than 50 watt of power for investigating the suitable parameters of 2 sets of the mirrors curvature radius [35]. Furthermore, Chananchida *et al* was applied the cutting machine to create the artificial leather for the cloth patterns [36].

Figure 8 CO_2 Laser cutting machine and its output examples

(Ref: https://thai.alibaba.com/product-detail/co2-laser-cutting-machine-price-for-textiles-clothing-fabric-60469235279.html)

5. CONCLUSIONS

Nowadays, the laser cutting technology is becoming more and more popular. It gains an important role, especially for the industrial production. The benefits are improving the speed and accuracy for the production. This corresponds to the end-products are impressive and cheapest. These results can thus be increased the number of the Thailand industries to use this technology in their production lines. Laser cutting machines are able to cut the material with higher speed, less heat, less vibration, less gas production, smaller cutting area and less twisted production, comparing to other cutting technology. Unfortunately, it's still expensive resulting in small number of the real usage. Accordingly, Thai government should encourage and support those industries to use the machine, for examples, decreasing tax, educating the benefits, encouraging industrial research collaborations.

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