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RESEARCH ARTICLE

AN OVERVIEW STUDY ON THE LASER TECHNOLOGY AND APPLICATIONS IN THE MECHANICAL AND MACHINE MANUFACTURING INDUSTRY

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ABSTRACT

Laser is considered one of the most influential inventions in the twentieth century and laser technology has been contributing in many areas of life. Today, in any field of manufacturing, laser technology also presents value and brings a range of specific benefits to the field such as machine manufacturing and mechanical tools. Thanks to the cutting edge cleaning ability, delicate welding lines, strong etching strokes, high power operation, accurate distance measurement capability, laser technology has gradually conquered and dominated the mechanical market, especially in the field of material handling, metal parts. Using lasers to cut metal creates highly detailed and continuous details, lines, shapes, patterns ... that open new avenues for the mechanical and machine-building industry. Using laser engraving machines, it will process complex and sophisticated details, saving time and manpower costs. High processing speed, smooth cutting surface and easy programming are the advantages that laser cutting technology offers to this industry. Lasers can be cut on different sheet metal or tubular surfaces at extremely fast speeds on tools, machine parts and even small-sized cutting workpieces. This paper will present an overview of laser technology and its common applications in the mechanical and machine-building industry. The analysis and evaluation in this paper will provide an update on the level of development of laser technology in the current industry age 4.0. In addition, it is a common picture and achievements of the machine manufacturing industry achieved with the support of "Light Amplification by Stimulated Emission of Radiation".

KEYWORDS

Laser technology, application technology, the machine manufacturing industry, laser cutting, laser distance measurement.

1. INTRODUCTION

Laser is the name of the first letters of the English term "Light Amplification by Stimulated Emission of Radiation". Laser is an artificial light source obtained by the amplification of light by radiation emitted by activating the elements of a corresponding physical medium [1]. Laser is a light that has more special properties than natural or artificial light and has very useful uses that can be applied in many fields of science and technology and life, creating a whole life. scientific and technical revolution after it was born. The advent of Laser originated from the Quantum Theory invented by the scientist A. Einstein in 1916. By 1954, British and American scientists simultaneously invented practical laser generator [2]. Human laser tests began in the 1960s. Since 1964, laser applications have been used in skin treatments [3].

Research on laser applications in medicine began in the 1960s to treat retinal detachment. Low-power lasers are used in physiotherapy for biological effects; High-power laser causes a burning effect for the treatment of spinal disc herniation [4]. Laser is an excellent surgical instrument (eye surgery, skin marks, tumors ...); people use lasers in acupuncture, to diagnose and treat diseases [5].

Laser is also applied in many science and technology fields: chemistry, semiconductor materials; fabricating metal materials; material processing; energy; architecture, art ... Excellent application of laser in industry is not too strange, from metal cutting, metal grooving ... to areas such as electricity, information technology. Using lasers to cut metal creates highly detailed and continuous details, lines, shapes, patterns ... that open new avenues for the mechanical and machine-building industry [6]. Using laser engraving machines, it will process complex and sophisticated details, saving time and manpower costs.

Today, almost in any field of manufacturing, manufacturing, laser technology presents value and brings a range of specific benefits to the field such as mechanical tool manufacturing. Thanks to cutting edge cleaning ability, delicate welding lines, strong engraving strokes, high-capacity operation [7]. Laser technology has gradually conquered and dominated the mechanical market, especially in the field of material handling and metal parts. The combination of phases allows the laser light to converge into a small point about the diameter of a wavelength (10^{-4}cm). So 1W laser can converge to have an intensity of 108 W / cm^2. Such a high convergence energy should use a high-power laser to drill, cut, engrave images with very high accuracy and speed [8].

Laser light is oriented so the beam retains its slenderness during the propagation process over very large distances. The laser beam has a power of only a few watts, which easily exceeds the distance between Earth and the Moon (384,000 km) and is returned to the Earth by the surface of the Moon. A beam of Laser Beams was originally the size of a pencil when it was about the size of a circle when it reached the Moon. This wide range of laser beams is only 0.001% of the Earth and Moon distance [9]. By measuring the laser's travel and return times astronomers can map the Moon. In the 1970s the Apollo astronauts left on the moon the special reflectors that were capable of reflecting laser beams. Reflected light is observed by telescopes on the ground. In this way astronomers can determine the orbit of the Moon to an accuracy of several centimeters. For the Earth-Moon distance, the accuracy is up to a tenth of a billion [7]. By performing these measurements from different continents astronomers can measure the drift rate of continental plates, which is several centimeters per year.

High processing speed, smooth cutting surface and easy programming are the advantages that laser cutting technology offers to the mechanical industry. Lasers can be cut on different sheet or tubular metal surfaces with very fast speeds on tools, machine parts and even small-sized cutting

workpieces[8]. Most metal materials can be processed by laser cutting technology. Thanks to the ability of cutting edge cleaning, delicate welding lines, strong etching strokes, high power operation, lasers have gradually conquered and dominated the mechanical market, especially in the field of material handling, metal and non-metallic parts [10]. High processing speed, smooth cutting surface and easy programming are the advantages that laser cutting technology offers to this industry [6]. Lasers can be cut on different sheet metal or tubular surfaces at extremely fast speeds on tools, machine parts and even small-sized cutting workpieces.

This paper presents an overview of the applications of laser technology in industry in general and the mechanical engineering industry in particular. New applications will be updated and evaluated in this paper to highlight the outstanding advantages of laser technology - a great invention of the twentieth century. At the same time, the author also proposed some applications of lasers in the new trend of the industrial revolution 4.0.

2. OVERVIEW OF LASER

2.1 The nature of laser

According to the basic concepts of quantum physics, when we project a beam of light into a physical environment, the beam of light will gradually weaken by being absorbed by the physical environment. The nature of the absorbed process is that light particles (photons) transmit the energy that activates the "molecular" material from the steady state A to a B state with a higher energy level. Because B is an unstable state, after a certain time, molecules at B level "jump" back to level A. While "jumping" it also emits a photon that carries energy with the energy it absorbs, in a "borrow what to pay" way. That is the phenomenon of radiation. However, these radiation photons are not much, because it is proportional to the number of molecules present at level B, but the number of molecules in state B is always less than the number of molecules in steady state A. This radiation is released in all directions freely so it is called free radiation [1].

When we make photons interact with molecules at high B, catch it back to A earlier and generate photons. The photons have energy levels and are equal to the energy levels of the photons of the projection source that are transmitted to it, which is the activated radiation [11]. When creating high-level activated radiation for radiating photons emitted continuously at the highest level. It is then selected and amplified so that they are transmitted in the same direction with the same properties that we will obtain in the laser beam. Thus, the principle of the laser generator is to make the light source on the laser active medium not weakened to enable continuous activation of the material element so that the number of molecules at level B is always higher than that at level A, so the number of radiation photons will be generated as much as possible. By special devices, this radiation source will be selected and amplified to emit a beam of monochromatic light, consisting of light rays of the same direction, with nearly equivalent wavelengths and high concentration [12]. That is the laser.

2.2 Principle of laser beam generator

The general construction principle of a laser machine includes: resonant chamber containing laser active substance, feed source and optical conduction system. In which the resonator with laser active substance is the main component (Figure 1).

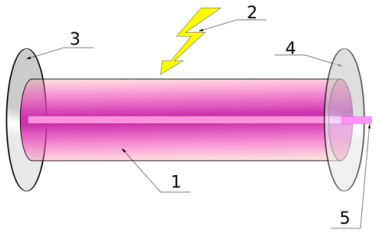

Figure 1: Basic structure and mechanism of laser operation [13]

1) Resonance chamber (irritated area) 2) Feeding source (pumped energy into irritated area) 3) Total reflector mirror 4) Semi-mirror mirror 5) Laser

The resonant chamber contains a laser active substance, which is a special substance capable of amplifying light by forced emission to produce a laser. When an incoming photon collides with the active substance, another photon pops up in the same direction as the incoming photon. On the other hand, the resonator has 2 shields on both ends, one reflects all photons on the fly; on the other hand, a part of the photon is partially reflected, which causes the photons to repeatedly collide with the laser substance repeatedly to create a large photon density. So the laser beam intensity is amplified many times [14]. The nature of the laser depends on the active substance, so it is based on the active substance to classify the laser.

2.2.1 Solid lasers

There are about 200 solids capable of being used as a laser active medium. Some common solid lasers: YAG-Neodym: active ingredient is Yttrium Aluminum Garnet (YAG) plus 2-5% neodymium, with a wavelength of 1060 nm in the near infrared spectrum. Can transmit continuously up to 100W or transmit pulses with frequencies of 1000-10000Hz [15]. Ruby (ruby): the active substance is the crystal Alluminium with chromium ions attached, has a wavelength of 694.3 nm in the red zone of white light. Semiconductor: the most common type is dioxin Gallium Arsenic with a wavelength of 890 nm in the near infrared spectrum.

2.2.2 Gas laser

He-Ne: the active element is helium and neon, has a wavelength of 632.8 nm in the red light spectrum in the visible region, with a small power, from one to several tens of mW. In medicine used as an intravenous laser, vascular stimulation [8]. Argon: active substance is argon gas, wavelength 488 and 514.5 nm. CO_2: 10,600 nm wavelength belongs to far infrared spectrum, emission capacity can reach megawatt (MW). In applied medicine as a scalpel [16].

2.2.3 Laser liquid

The active medium is liquid, most commonly colored laser.

2.2.4 Properties of lazer

High orientation: the laser beam emits almost a parallel beam so it is capable of radiating thousands of kilometers without being dispersed. Monochrome is very high: the light beam has only one color (or one wavelength). Therefore, the laser beam is not scattered when passing through the interface of the two environments with different refractive index. This is the most special property that no light source has. This property is very important because the laser's effect when interacting with matter, with biological organizations depends on this monochromatic degree. Synchronization of photons in the laser beam: Able to produce extremely short pulses: milliseconds (ms), nanoseconds, picoseconds, allowing the concentration of extremely large laser energy in extremely short time.

2.2.5 Operating modes

Lasers can be constructed to operate in continuous wave (CW) or pulsed operation. This leads to fundamental differences when building laser systems for different applications [17].

2.2.5.1 Continuous wave mode

In continuous wave mode, the power of a laser is relatively constant over time. The reversal of the electron density required for laser activity is maintained continuously by a constant source of energy pump.

2.2.5.2 Pulsed operation mode

In pulsed wave mode, the laser power is constantly changing over time, with the "closed" and "interrupt" phases characterized by the highest possible energy concentration in the shortest possible time. Laser knives are an example, with sufficient energy to provide the necessary heat, they can vaporize a small amount of material on the surface of the specimen in a very short time. However, if the same energy is available but contacting the specimen for a longer period of time, the heat will have time to penetrate deeper into the sample so that the material evaporates less. There are many methods to achieve this, such as: Q-switching method; Modelocking method; Pulsed pumping method.

3. APPLICATIONS OF LASERS IN THE MECHANICAL INDUSTRY

In the field of mechanical tool manufacturing, laser technology also plays a very important role. Thanks to the ability to clean cutting edges, delicate welding lines. Today, almost in any field of manufacturing, manufacturing, laser technology presents value and brings a range of specific benefits to the field such as mechanical tool manufacturing [17]. Thanks to the ability of cutting edge cleaning, delicate welding lines, strong etching strokes, operating with high capacity, laser technology has gradually conquered and dominated the mechanical market, especially in the field of material handling, metal parts.

3.1 Laser cutting application

High processing speed, smooth cutting surface and easy programming are the advantages that laser cutting technology offers to the mechanical industry. Lasers can be cut on different sheet or tubular metal surfaces with very fast speeds on tools, machine parts and even small-sized cutting workpieces. Most metal materials can be processed by laser cutting technology [18]. Laser cutting machines are currently being used to optimize processing and manufacturing processes in all industries such as electronics, auto, car, motorbike, medical, steel, wood and printing, packing.

Laser cutting machines are extremely ideal when you need an optimized cutting solution on processing time. Laser cutting machine with modern technology with high accuracy and fast processing time, contributing to the process of creating perfect products. In addition to conventional materials (metal, non-metallic), laser technology has now been applied to most other difficult-to-handle materials on the market today such as HPL sheets, decals, foam paper, rubber, fabric, yarn, textile materials, double-sided adhesives, cushions, plastic materials, hard-to-abrasive materials, anti-corrosion adhesives [19].

Laser cutting machines using high-intensity lasers are guided through the lens system to the surface of the material to cut or engrave in pre-programmed and multi-dimensional shapes. Accurate laser technology can create holes, slots with significantly smaller diameters (with smaller tolerances) than traditional cutting methods. This is a non-collision cutting process, without the use of hard materials, so it does not create wear costs and replacement time [20].

3.1.1 The basic principle of laser cutting can be summarized as follows (Figure 2)

1. A high-energy beam produced by a laser generator will be focused on the workpiece surface by the lens system.

2. This beam heats the material and creates a local molten material area, usually smaller than 0.5mm in diameter.

3. The molten material is pushed out of the machining zone by a high pressure, coaxial stream of gas with the laser beam. For some materials, this gas flow accelerates the cutting process by chemical and physical action.

4. The locally melted material area is moved along the detailed surface in an orbit and produces a cut. This motion is accomplished by moving the focused laser beam through the CNC mirror system or the two-way X-Y material plate mechanical movement on the CNC table. There are also machines that design both types of movements, when the laser beam is moved in one direction and the workpiece is moved in the other. Fully automated systems allow for 3D shapes to be cut.

From the energy atoms created above thanks to the flat beams of converged beams controlled by optical systems located in laser machines that help these beams focus on the points in the most accurate way according to the figure. The form has been shaped through the microprocessor of the computer and impacts the surface of the product to be processed to create cutting lines or engraving according to the drawings and constructions imported from the computer.

High-energy laser beams generate heat at the contact surface, causing the material to heat up and drain or punch holes in the materials depending on the processing program you have installed for machining. Therefore, the laser cutting machine can cut the lines extremely accurately and sophisticatedly than the traditional manual processing method by hand or by lathe, engraving cutting machine. Not only that, the processing speed of laser machines is also much faster than other methods.

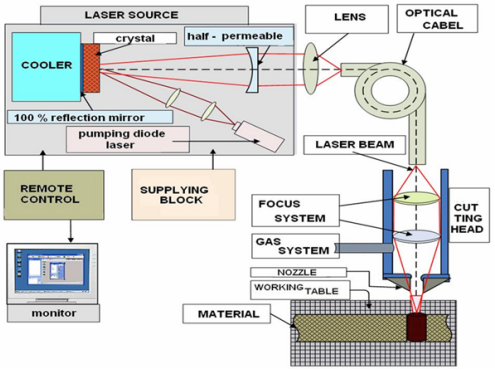

Figure 2: Principle of laser cutting machine [21]

3.1.2 Characteristics

Lasers can cut a wide range of materials but most commercial laser cutting systems are now made with metal. Laser metal cutting requires a high-energy density laser beam to transfer energy into the cutting zone faster than the heat transferred. Along with that, the support gas flow will push molten metal out of the cutting zone[4]. Carbon steel is the most easily cut metal material by laser. Low alloy steel types such as AISI 4140, 8620, ... have cutting conditions similar to carbon steel. The content of alloy in steel increases, the cutting process becomes more difficult. With tool steel with high tungsten content, the cutting speed is very slow and slag is available [22].

Aluminum is difficult to cut with lasers because aluminum reflects a large amount of laser and the amount of heat transferred into large and fast details. If the laser focus is adjusted incorrectly, the beam may be reflected back into the spray system, causing damage to the optical components. Whereas pure copper is harder to process than aluminum. Copper alloys also behave similarly to aluminum. Co-board base alloys have very high hardness, high heat resistance and good abrasion resistance. However, they are easy to cut with lasers. However, it is necessary to consider microscopic cracks generated on the surface of the details when laser is cut.

3.2 Laser distance measurement application

People use lasers to measure distances and global measurements. In communications, it is used for terrestrial communication and artificial satellite positioning, control of takeoff and landing aircraft. In science and technology, using a large-capacity laser to "pump" energy to the plasma environment to the temperature needed in fusion and uranium enrichment. In agriculture, laser can be used to stimulate growth, seed treatment to increase germination rate ... In the field of environmental protection, laser applications can be used to analyze and check environmental pollution [10].

Laser distance measurement method: Distance measurement method based on flight time measurement TOF (time of flight); Analysis method based on processing interference pattern or diffraction; Measure distance based on angle measurement; Measure distance based on the principle of phase modulation [23]. The general principle of phase modulation is to measure the difference between the phase of the light emitted with the light received after feedback from the object. However, there is no one photodetector that can respond to the change of direct frequency of light up to 100THz. Therefore, the phase modulation method using the direct frequency of light cannot be produced. Therefore, to be easily measured, we have to modulate the light frequency to a lower frequency that optical and electronic receiver components can meet. So use the sine wave modulation method to control the diode laser and use the photodetector to capture the feedback laser light and then measure the phase shift from the transmitter and receiver to calculate the distance. To measure the phase, it is common to apply Heterodyne technique to create a lower frequency wave [24].

Laser distance meter is a specialized distance measuring device that uses lasers to measure complicated angles. Allows measurement of horizontal and diagonal lines in an angle. Easy to use, use buttons to add or subtract, calculate area, volume right on the machine surface. Operation Principle Laser Distance Measuring Machine: Distance meter Measure the time difference between the emitted laser pulse and the feedback pulse then multiply at the speed of light (300,000km / s), take the result of dividing 2, get the distance to be measured. All calculations are quickly manipulated directly through the machine's keys and screens, you can also store measured data to perform calculations later. The method used to measure distance depends on the accuracy and distance capability required of the device. Measurement principles include triangulation, time-of-flight measurement, pulse-type time-of-flight systems, and modulated beam systems [16].

For distances of a few inches with high accuracy requirements, **"triangulation" sensors** measure the location of the spot within the field of view of the detecting element. **Time of flight sensors** derive range from the time it takes light to travel from the sensor to the target and return. For very long range distance measurements (up to many miles) "time-of-flight" laser rangefinders using pulsed laser beams are used. **Modulated Beam Systems** use the time light takes to travel to the target and back, but the time for a single round-trip is not measured directly. Instead, the strength of the laser is rapidly varied to produce a signal that changes over time (Figure 3) [25].

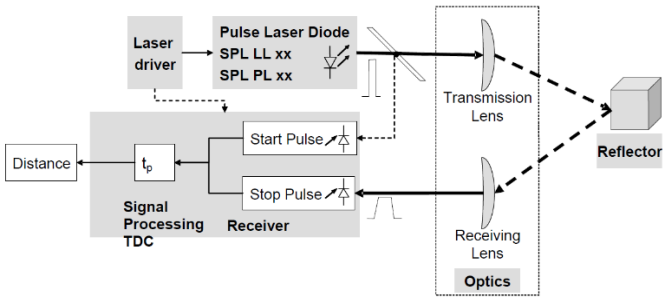

Figure 3: Working principle of laser distance measuring device [25]

3.2.1 Triangulation measurement principle

One method for accurately measuring the distance to targets is through the use of laser triangulation sensors. They are so named because the sensor enclosure, the emitted laser and the reflected laser light form a triangle. The laser beam is projected from the instrument and is reflected from a target surface to a collection lens. This lens is typically located adjacent to the laser emitter. The lens focuses an image of the spot on a linear array camera (CMOS array). The camera views the measurement range from an angle that varies from 45 to 65 degrees at the center of the measurement range, depending on the particular model. The position of the spot image on the pixels of the camera is then processed to determine the distance to the target. The camera integrates the light falling on it, so longer exposure times allow greater sensitivity to weak reflections [26]. The beam is viewed from one side so that the apparent location of the spot changes with the distance to the target.

The AR600 triangulation displacement sensor is patented and much can be learned by reading the patent (USPTO 6,624,899). Triangulation devices are ideal for measuring distances of a few inches with high accuracy. Triangulation devices may be built on any scale, but the accuracy falls off rapidly with increasing range. The depth of field (minimum to maximum measurable distance) is typically limited, as triangulation sensors can not measure relative to their baseline, the distance between the emitter and the detector. The exposure and laser power level are typically controlled to optimize the accuracy of the measurements for the signal strength and environmental light level measured. The range data may be internally averaged over multiple exposures prior to transmitting if the sample rate is set appropriately.

3.2.2 Time of flight

Modulated beam systems also use the time light takes to travel to a target and back, but the time for a single round trip is not measured directly. Instead, the strength of the laser is rapidly varied to produce a signal that changes over time. The time delay is indirectly measured by comparing the signal from the laser with the delayed signal returning from the target. One common example of this approach is “phase measurement” in which the laser’s output is typically sinusoidal and the phase of the outgoing signal is compared with that of the reflected light [17]. Phase measurement is limited in accuracy by the frequency of modulation and the ability to resolve the phase difference between the signals. Some modulated beam rangefinders work on a range-to-frequency conversion principle, which offers several advantages over phase measurement. In these cases, laser light reflected from a target is collected by a lens and focused onto a photodiode inside the instrument.

The resulting signal is amplified up to a limited level and inverted, and used directly to modulate a laser diode. The light from the laser is collimated and emitted from the center of the front face of the sensor. This configuration forms an oscillator, with the laser switching itself on and off using its own signal. The time that the light takes to travel to the target and return plus the time needed to amplify the signal determines the period of oscillation, or the rate at which the laser is switched on and off. This signal is then divided and timed by an internal clock to obtain a range measurement. The measurement is somewhat nonlinear and dependent on signal strength and temperature, so a calibration process can be performed in the sensor to remove these effects. Modulated beam sensors are typically used in intermediate range applications, for distances from a few inches to several tens of feet on uncooperative targets. With cooperative targets, like reflectors, range can be extended to several hundreds or thousands of feet.

3.2.3 Confocal chromatic

Acuity’s most accurate and most resolute distance sensor employs a unique measuring principle, confocal chromatic sensing. Unlike our time-of-flight and triangulation sensors which use lasers, the CCS Prima Confocal sensors use a white light source to accurately measure the distance to surfaces. Some models are accurate to within 20 nanometers. Additionally, this technology permits measurement and profile of transparent materials like glass, lenses, liquids, etc [15].

The essence of our confocal chromatic imaging principle is the accurate detection of colors from light that is reflected back from target surfaces. The white light is focused onto the target surface by a multi-lens optical system. These lenses disperse the light into monochromatic stages (colors) along the measurement axis. A specific distance to the target is assigned to each color’s wavelength in a factory calibration. Only the wavelength which is exactly focused on the target is used for the measurement. This light reflected from the target surface is transmitted from the probe, through a confocal aperture and onto a spectrometer which detects and processes the spectral changes and calculates distances. These distance measurements are transmitted at high speed via ethernet communications protocol.

4. CONCLUSIONS

Laser is a modern technology that brings many benefits in today's life. Industrial lasers are the main types of lasers used in industry such as material processing, machine manufacturing, metal cutting by laser or engraving on all materials. Most of lasers are applied in manufacturing and industry. Use the power level from medium (several tens of W) to high power level (several kW) to process metal or nonmetallic materials. Currently there are many different types of lasers used in materials processing, mechanical engineering and manufacturing. Laser used in sheet metal cutting: this application is particularly meaningful to the mechanical engineering industry. Because high-power laser systems can even cut sheets of steel up to several tens of millimeters with machining marks with only hair fibers, the products create high sophistication, not scorched .... Thanks to the laser, the mechanical engineering time is significantly shortened. Laser in auxiliary industry: applications in this field must include such as marking or marking, printing production information, production date, expiry date or engraving metal molds, stainless steel grooving. Laser is considered one of the most influential inventions in the twentieth century and laser technology is gradually becoming popular and contributing to many areas of life. Thanks to it, all work is done quickly, more efficiently, ensuring accuracy and sophistication. In the future, lasers will become a powerful war tool and a technical-technological arena of world powers.

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