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Laser Cutting Technology in the World of Medicine and Science

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Abstract- Laser cutting technology has emerged as a transformative innovation that significantly impacts the medical and scientific fields. Its ability to cut and shape materials with exceptional precision has made it invaluable in various applications, including surgical procedures, the fabrication of implants, and the development of micro devices such as lab-on-a-chip systems. This article explores the fundamental principles of laser cutting technology, its primary applications in medicine and science, and the benefits and challenges associated with its use. A review of existing literature reveals that laser cutting enhances both the quality and efficiency of medical procedures and scientific research. By enabling the creation of highly precise, customized components, laser cutting reduces risks and improves the overall effectiveness of treatments and diagnostic tools. Despite these advantages, the technology faces challenges such as the high cost of equipment, the need for skilled operators, and the limitations in cutting certain materials or thicknesses. However, as laser technology continues to advance, it is expected to play an increasingly critical role in the future of healthcare and scientific innovation. The ongoing refinement of laser cutting techniques presents promising opportunities for the development of new, more precise, and less invasive technologies. Ultimately, laser cutting technology holds great potential in advancing medical treatments, improving research outcomes, and supporting the development of cutting-edge technologies that will drive progress in both the healthcare and scientific sectors.

Keywords: *electric field, vacuum media, distribution pattern*

1 Introduction

Technology has become a key factor in transforming various aspects of human life, from industry and communications to healthcare. One technological innovation that has developed rapidly in recent decades is laser cutting. Initially created to meet the demands of the manufacturing industry, which requires high-precision material cutting, this technology has now transcended its initial limitations and reached the medical and scientific worlds, making significant contributions (Sugiarto, 2019).

Laser cutting is a method that uses a focused, high-energy laser beam to cut materials. This method allows for extremely high-precision cuts, fast processing speeds, and minimal distortion of the surrounding material (Nasir, 2023). Because of these advantages, laser cutting has become a highly useful tool in applications that require extreme accuracy and care, such as those in medicine and scientific research (Harjono, 2020).

In the medical field, the application of laser cutting technology has revolutionized various clinical and surgical procedures. One of its most well-known uses is in ophthalmology, where the LASIK procedure is used to correct vision problems (Hairi & Meyzia, 2023). Furthermore, this technology is also used in laparoscopic surgery, which involves removing tumors with very small incisions, dentistry, and dermatology for the removal of abnormal skin tissue. This technology not only increases the effectiveness of medical procedures but also speeds up patient recovery and reduces the risk of post-operative infection (Putra, 2021).

In the world of science, laser cutting technology plays a crucial role in the manufacture of laboratory cutting is used to create micropaths on laboratory chips used in various diagnostic studies and cell experiments. Its ability to cut materials with micron thicknesses cutting is used to create micropaths on laboratory chips used in various diagnostic studies and cell experiments. Its ability to cut materials with

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micron thicknesses. Its ability to cut materials with micron thicknesses, such as glass, thin metals, and polymers, makes this technology invaluable in cutting-edge research that requires extremely tight dimensional control (Wijaya, 2022).

Furthermore, in materials research and biomedical engineering, laser cutting enables the creation of medical implants or tissue structures tailored to each patient's individual needs. This process supports personalized treatment approaches, which are increasingly becoming a focus in future healthcare developments (Fauza, 2025). The flexibility and high precision of laser cutting technology also make it easier for scientists to prototype new medical devices more quickly and efficiently (Anwar, 2023).

The term "laser" stands for Light Amplification by Stimulated Emission of Radiation. Since its discovery in 1960 by Theodore Maiman, the laser has evolved from a mere scientific novelty to a vital tool in modern medicine. Early medical lasers were primarily used for experimental purposes and basic procedures, but technological advances have expanded their applications exponentially (Maiman, 1960). By the 1980s, lasers had become essential in ophthalmology, dermatology, and surgery. The development of laser types, such as the CO2 laser, the Neodymium (Nd) laser, and the excimer laser, has facilitated their use in a wide range of medical procedures. The precision, control, and minimally invasive nature of lasers have made them essential in contemporary medical practice (Santosa, 2024).

2. Research Methodology

This research was conducted using a literature review method, which involves collecting data and information from various written sources relevant to the topic of laser cutting technology in medicine and science. This approach is qualitative and descriptive, in which the author attempts to examine, understand, and explain the use of this technology based on available scientific references (Pratiwi & Sahal, 2024). The sources used in this research include national and international scientific journals, textbooks, articles from research institution websites, patent documents, and official publications from medical and technological institutions. The selected literature was limited to works published between 2010 and 2025 to ensure the information presented remains current and relevant (Rahardjo, 2021).

The analysis phase was carried out through an initial identification process to filter documents relevant to the study's focus. Next, the collected information was categorized based on the application aspects of laser cutting technology, both in the medical field—such as precision surgical procedures, prosthetic printing, and ophthalmology—and in science, for example, in materials research and microstructural engineering. The results from these various sources were then synthesized to form a comprehensive understanding of the development of this technology, its benefits, and the challenges still faced in its implementation (Yuliana, 2022).

To maintain data quality and validity, the authors only used references from trusted sources that had undergone peer review. With this approach, the research results are expected to provide a comprehensive overview of the contribution of laser cutting technology to today's medical and scientific worlds (Hasanah, 2023).

3. Results and Discussion

A CNC laser cutting machine is a technological device that utilizes a high-powered laser beam to cut at specific points. Cutting instructions are controlled directly by a computer, enabling the process to run automatically through a CNC (Computer Numerical Control) system. This machine is equipped with DSP (Digital Signal Processing) technology that enables cutting and engraving of materials. Operation can be done automatically or manually, with design and parameter settings via a portable monitor. The three main functions of a CNC laser cutting machine are cutting, engraving, and marking (Salam et al., 2020). The development of laser technology is currently very rapid and has been utilized in various sectors such as the manufacturing industry, healthcare, art, commerce, and printing. Although there are various types of lasers on the market, the most common type used in the manufacturing world is Laser Cutting (Asroni, 2022).

Figure 1:CNC laser cutting machine

3.1 How CNC Laser Cutting Machines Work

a. Main Engine
The main engine is the mechanical part responsible for moving the XYZ axes and supporting the material cutting process. This laser cutting machine is equipped with high-quality components to ensure optimal precision and stability, allowing for accurate movements according to the existing control system.

b. Laser Generator
The laser generator is the main source of laser light in a laser cutting machine and one of the most expensive components in this machine.

c. Laser Lens
Laser lenses maintain the stability of the laser beam path as planned. High-quality lenses can focus the beam without causing angular deviation.

d. CNC System
The CNC system plays a role in setting up computer programming that controls the movement of the laser axis.

e. Power Supply
The power supply is a source of electrical power for the laser cutting machine, which functions to connect the laser generator, cutter, and electrical system.

f. Laser Cutting Head
The cutting head consists of a nozzle, a laser lens and a direction sensor, which regulates the movement in the Z axis according to the program. The height of the cutting head must be adjusted to the type and thickness of the material.

g. Control Panel
The control panel on the laser machine regulates and controls the material cutting process.

h. Drive Motor
The drive motor is the primary system that powers the machine. There are two commonly used types of motors: stepper motors and servo motors.

i. Chiller
The chiller functions to keep the laser generator temperature stable, preventing overheating, by providing cooling water to ensure optimal generator operation.

3.2 Principles of Laser Technology

Lasers operate on the principle of stimulated emission, where an external energy source excites electrons in a medium, causing them to emit photons coherently. The coherence, monochromatic nature, and high intensity of laser light make them suitable for a wide range of medical applications. Coherence: Lasers emit light waves that are in phase, allowing for precise focusing. Monochromaticity: Lasers emit light with a single wavelength, which can be tailored for specific applications. High Intensity: Lasers can deliver concentrated energy, allowing for precise cutting, ablation, or freezing of tissue (Siregar, 2020).

3.3 Laser Cutting Working Principle

The basic principle of laser cutting involves sending a high-powered laser beam to the surface of the material to be cut, controlled by a computer. This technology is capable of cutting complex shapes that are difficult to achieve using CNC milling machines. The resulting cuts are highly precise, with an accuracy of up to 0.001 mm. The laser diodes used in this cutting process operate at visible light frequencies of around 10^{14} to 10^{15} Hz, or much higher than microwave frequencies. This laser beam is effective for cutting various types of materials such as acrylic, plywood, fabric, and leather (Roziq Husen & Iskandar, 2023).

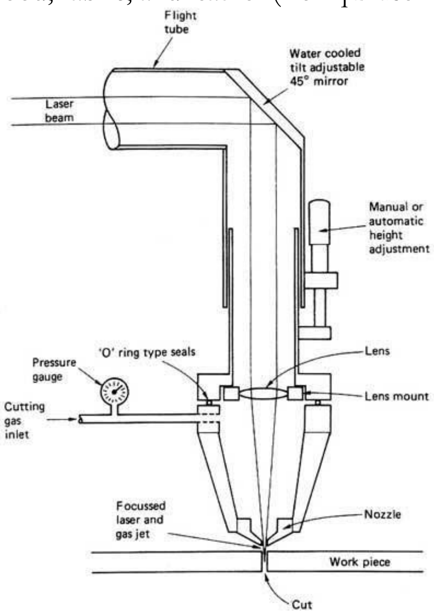

Figure 2: Laser Cutting Working Principle

1) The laser resonator source produces a laser beam with a diameter of about ¾ inch.
2) The resulting light is then directed using a refracting lens so that it remains on the correct path without experiencing deviation.
3) Next, the laser beam is guided towards a focus lens to concentrate the laser energy maximally.
4) After going through the focusing process, the laser beam is ejected through the nozzle along with a jet of high-pressure gas.
5) The combination of laser beam and gas jet automatically cuts the work material according to the pattern determined by the CNC system.

3.4 Laser Cutting Parameters

The laser cutting process involves several important parameters, such as the laser beam focal point, gas flow velocity, and cutting speed. This study aims to determine the optimal combination of parameters to produce a cut surface with a low level of roughness. Surface roughness analysis was performed using the Taguchi method. The cross-sectional structure of the laser cut results exhibits certain characteristics (Lubis et al., 2023). Laser cutting technology works by concentrating radiant energy at a single point, known as the "point of maximum energy," to increase the temperature precisely, thus enabling it to cut various types of materials. In a laser generator system, the main components consist of an active medium (in the form of atoms or molecules) placed between two mirrors, and an excitation source responsible for triggering the formation of a laser beam. This process occurs when the excitation source causes atoms or molecules in the active medium to become excited and emit photons. These photons are released when electrons return to a lower energy level after excitation, producing a laser beam (Rizal et al., 2022).

In the medical world, laser cutting has been widely used in various procedures and medical devices. One of the most prominent applications is in ophthalmological surgery, specifically in the LASIK (Laser-Assisted In Situ Keratomileusis) procedure, where a laser is used to reshape the cornea to correct refractive errors such as nearsightedness or farsightedness. Furthermore, this technology is also used to cut soft and hard tissue during surgery with a very high degree of precision, reducing bleeding and the risk of infection, and accelerating the healing process. In orthopedics and dentistry, laser cutting also plays a crucial role in the creation of implants and prosthetics tailored to the patient's anatomy using biocompatible materials such as titanium and zirconia (Wijanarko, 2021).

Measurement accuracy in cutting PET plastic material shows a difference between the design dimensions and the resulting cut. However, increasing cutting speed does not significantly affect the dimensions of the resulting cut. The results of the comparison between the design dimensions and the resulting cut are shown in Figure 7.

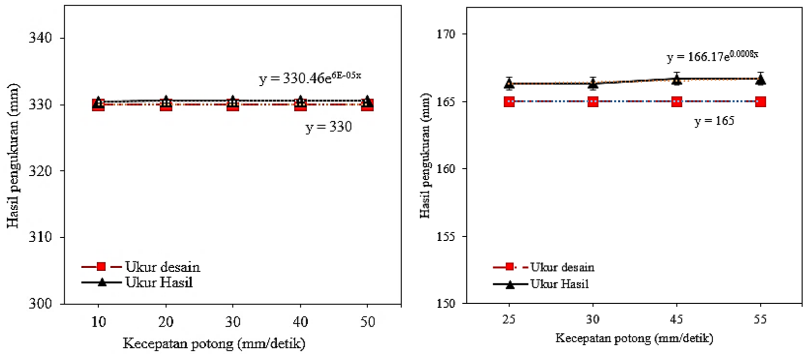

Figure 3: Difference between design size and cutting result size (a) APD face shield (b) APD cloth mask.

Based on Figure 3, the size difference between the design and the cutting results is still within the permissible tolerance limits, which are ±1 mm for PET plastic material and ±2 mm for fabric material. Measurements show that the difference is relatively small, with a value of less than 1 mm for PET plastic and less than 2 mm for fabric (Wibowo & Setiawan, 2021). This difference is represented by the mathematical equation $y = 330.46e^{(-0.0006x)}$ for PET plastic, with an average difference of 0.52 mm and a standard deviation of 0.05. Meanwhile, for fabric material, the equation $y = 167e^{(0.0004x)}$ is obtained, with an average difference of 1.50 mm and a standard deviation of 0.47 (Lestari & Nugraha, 2022).

The size difference between the design and the cutting result does not cause damage or product rejection (Pratama & Suryawan, 2020). Furthermore, increasing the cutting speed of the laser machine does not affect the position of the laser beam's focal point on the material or disrupt the stability of the nozzle. With an average size difference of 0.52 mm for PET plastic and 1.50 mm for fabric, the cutting results are considered within acceptable limits, especially by manufacturers of personal protective equipment (PPE) such as cloth masks and face shields made from PET (Suryanto & Hidayat, 2021). On the other hand, electrical energy consumption (in kWh) increased when the cutting speed was increased from 10 to 20 mm/s. Electricity consumption tended to be stable at speeds of 20 to 40 mm/s, while accompanied by an increase in the number of production per hour. If the speed exceeds 40 mm/second, electrical energy consumption increases again in proportion to the production volume, according to the equation $y = 21.769e^{(0.3145x)}$, where y is electrical energy consumption and x is cutting speed (Prasetya & Yuliana, 2020).

The highest production increase, 48.3%, occurred when the cutting speed increased from 10 to 20 mm/s. Furthermore, production increased by an average of 20% as cutting speed and energy consumption increased. Figure 4(a) shows that the ideal cutting speed for PET is in the range of 20–40 mm/s because there is no surge in power consumption. Figure 4(b) displays the same pattern for cutting polyester fabric.

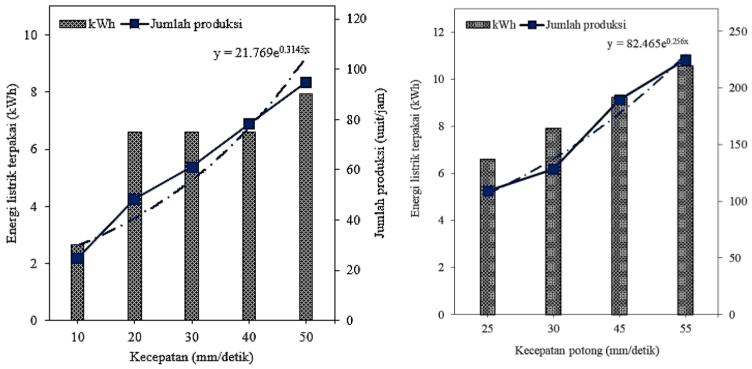

Figure 4: Cutting speed against electrical energy consumption (a) APD face shield

a. PPE cloth masks

The highest increase in production was recorded at 32.2% when the cutting speed was increased from 30 mm/s to 45 mm/s. After that, the average production increase was 15%, following the equation model y = 82.465e0.256x. The increase in cutting speed also had an impact on increasing electrical energy consumption by an average of 14.5%. The ratio between the increase in production output and electrical energy consumption (in kW) reflects the level of energy productivity. At a cutting speed of 40 mm/s, a significant increase in energy productivity was recorded (S. Slamet et al., Journal of Mechanical Design and Testing, 3(2), 2021, pp. 83–92). Where every 1 kW increase will increase the production quantity by 11-12 units in cutting PET plastic for PPE face shields and 20-21 units in fabric materials for PPE masks. The use of electrical energy consumption appears to be starting to stabilize at a cutting speed of 40 mm/s for cutting PET plastic materials and a cutting speed of 45 mm/s for cutting polyester fabric materials.

At a cutting speed of 40 mm/s for PET material used in face shield manufacturing, there was a 16.7% increase in electrical energy consumption, which is equivalent to a 22.03% increase in productivity. Meanwhile, for polyester fabric for PPE masks, energy consumption increased by 12.5% with a 20.8% increase in productivity at a cutting speed of 45 mm/s. Figure 5 (a) displays the relationship between electrical energy consumption and energy productivity for PET material for face shields, while Figure 5 (b) shows a similar relationship for polyester fabric for PPE masks (Slamet, S., Nugroho, A., & Yuliani, E, 2021).

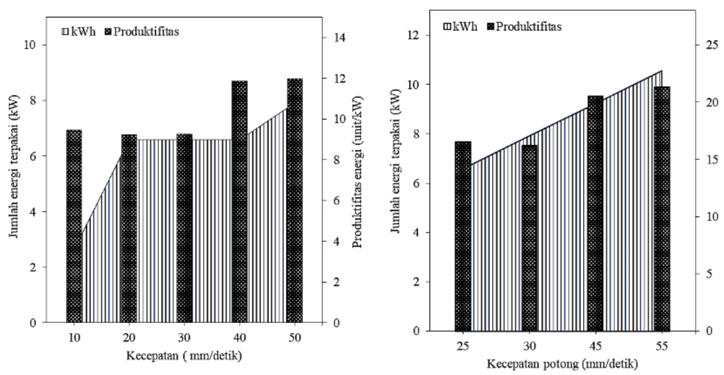

Figure 5: Electrical energy consumption against energy productivity (a) PET APD face shield (b) Polyester fabric APD mask.

On the other hand, in the fields of science and research, this technology plays a vital role in the microfabrication process and the development of micro-sized laboratory devices, such as microfluidic devices and labs-on-a-chip. Laser cutting enables researchers to create channels and microstructures in materials such as glass, polymers, or silicon with high accuracy and without the need for physical molds.

This is particularly useful in experiments that require small, closed systems, such as in biotechnology or analytical chemistry research. Furthermore, laser cutting is also used in material surface modification, photonic processing, and material structure analysis through ablation methods (Lestari, 2022).

Advances in modern laser technology, such as ultrashort pulse lasers and femtosecond lasers, have increased the effectiveness and efficiency of these applications. These new-generation lasers enable cutting without significant thermal effects, making them ideal for sensitive materials such as biological tissue or micro-sized electronic components. Integration with digital and automation technologies such as CAD (Computer-Aided Design) also accelerates production processes and improves design accuracy (Nugroho, 2023). With all the advantages it offers, it can be concluded that laser cutting technology is not just a material processing tool but has become an integral part of the technological revolution in the medical and scientific fields. While challenges remain in terms of cost and the need for skilled operator training, innovation trends indicate that this technology will continue to develop and have a broader positive impact in the future (Mahendra, 2024).

4. Conclusion

Laser cutting technology has become a key innovation driving progress in medicine and science. Its ability to cut and shape a variety of materials with high precision makes it ideal for applications that require high accuracy, such as ophthalmic surgery, implant manufacturing, and the development of microdiagnostic devices. Not only does this technology speed up work processes and increase efficiency, it also produces cleaner, less risky results, and can be tailored to individual patient or research needs.

In the scientific field, laser cutting opens up significant opportunities for the development of micro- and nanoscale technologies previously difficult to achieve with conventional methods. Meanwhile, in the medical world, its application has been proven to improve the quality of care and accelerate patient recovery. With the continued development of laser machine types and capabilities, including integration with digital technology and automation, it is certain that laser cutting will play an increasingly vital role in providing innovative solutions for healthcare and scientific research in the future.

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