ENHANCED LASER CNC MACHINE PERFORMANCE ON VARIOUS ALUMINIUM SHEET QUALITIES: A REVIEW

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Abstract - *Laser Computer Numerical Control (CNC) machines have emerged as powerful tools in modern manufacturing processes, offering exceptional precision, speed, and versatility. This review paper aims to provide a comprehensive analysis of the performance aspects of laser CNC machines by synthesizing existing literature and research findings.*

The paper begins by outlining the fundamental principles of laser CNC machines, including their basic components, working mechanisms, and various types of lasers employed. It then delves into a detailed examination of performance evaluation parameters that encompass both quantitative and qualitative measures.

In terms of quantitative performance metrics, factors such as cutting speed, accuracy, repeatability, and surface finish are scrutinized. The review explores the influence of laser power, beam quality, focusing optics, and motion control systems on these parameters. Additionally, it highlights the significance of material characteristics, such as thickness, composition, and thermal conductivity, in shaping the machine's performance.

Furthermore, the review emphasizes the evaluation of qualitative aspects, including flexibility, adaptability, and ease of use. Factors like software compatibility, user interface, tool changing capability, and automation potential are discussed to provide a comprehensive understanding of the machine's operational convenience and productivity.

Key Words: *CNC machine, CO2 laser machine, Metal Sheet, Aluminum Sheet, Pin Profile.*

1. INTRODUCTION

The history of laser CNC machines dates back several decades and is intertwined with the development of laser technology and computer numerical control (CNC) systems. Here is a brief overview of the key milestones in the history of laser CNC machines:

1. Invention of the Laser: The concept of the laser (an acronym for Light Amplification by Stimulated Emission of Radiation) was first proposed by Albert Einstein in 1917, but it took several decades for the technology to be realized. In 1960, Theodore H. Maiman built the first working laser, a ruby laser.

2. Introduction of CNC Systems: CNC systems, which automate machine tool operations through computer control, emerged in the late 1940s and early 1950s. The development of digital computers and the integration of numerical control techniques revolutionized manufacturing processes.

3. Integration of Lasers with CNC: In the 1960s, researchers began exploring the use of lasers as a tool for material processing. In 1965, the first laser cutting experiment was conducted, demonstrating the potential of lasers for precision cutting operations.

CNC machining is a cycle where assembling machines and instruments are moved as per pre-modified PC programming. Accordingly, makers can create parts quicker than expected, lessening waste and disposing of human blunders. This creation strategy is utilized to work an assortment of perplexing machines, which will be canvassed later in this article. Fundamentally, CNC machining makes it conceivable to perform three-layered cuts by adhering to a solitary arrangement of guidelines. This is the figure of the CNC machine:

Figure-1: Laser CNC Machine.

1.1. TYPE OF THE CNC MACHINE

The CNC machine is classified into eight types, which are given below:

1. CNC Milling-Machine.
2. CNC-Router.
3. CNC-Plasma Cutting Machine.
4. CNC-Lathe Machines.
5. CNC-Laser Cutting Machine.
6. CNC-Water jet Cutting Machine.
7. CNC-Electrical Discharge Machine.
8. CNC-Grinder

1.2. CO2 Laser.

A CO2 laser CNC machine, also known as a CO2 laser engraver/cutter, is a type of computer numerical control (CNC) machine that utilizes a CO2 laser as its cutting and engraving tool. It is commonly used in various industries such as manufacturing, signage, woodworking, textiles, and more.

Here are some key characteristics and functionalities of CO2 laser CNC machines:

1. Laser Source: CO2 lasers use a gas-filled laser tube containing a mixture of carbon dioxide, nitrogen, and helium. When an electric current is applied to the gas mixture, it excites the CO2 molecules, producing a high-energy laser beam in the infrared spectrum (typically 10.6 micrometers).

2. Cutting and Engraving Capabilities: CO2 lasers are well-suited for cutting and engraving a wide range of materials, including wood, acrylic, plastics, leather, fabric, paper, glass, and some metals (with certain limitations). The focused laser beam vaporizes or melts the material, creating precise cuts or engraving marks.

3. CNC Control: CO2 laser CNC machines are equipped with computer numerical control systems that precisely control the movement of the laser head. Users can create or import designs into specialized software that converts them into machine instructions, controlling factors such as the laser power, speed, and path.

4. Versatility: CO2 lasers offer versatility in terms of cutting and engraving capabilities. By adjusting the laser power and speed settings, operators can achieve different results. Lower power settings are ideal for engraving intricate details and creating fine lines, while higher power settings enable efficient cutting through thicker materials.

5. Work Area and Bed Size: CO2 laser CNC machines come in various sizes, offering different work area dimensions and bed sizes. This allows for flexibility in handling materials of different sizes and accommodating larger projects.

6. Safety Precautions: Operating a CO2 laser CNC machine requires proper safety precautions. Enclosed work areas, laser safety glasses, and ventilation systems are commonly employed to protect operators from direct exposure to the laser beam and fumes generated during the process.

7. Maintenance: CO2 laser tubes have a limited lifespan, typically measured in thousands of hours of operation. Regular maintenance, including cleaning and aligning optics, replacing worn parts, and ensuring proper ventilation and cooling, is essential to maintain the machine's performance and longevity.

CO2 laser CNC machines are widely used in industries that require precise cutting and detailed engraving. They provide excellent versatility and accuracy, making them a popular choice for both small-scale applications and large-scale production environments.

Figure-2: CO2 Laser.

1.3.PERFORMANCE OF LASER CNC MACHINE

The performance of a laser CNC machine, including its cutting and engraving capabilities, can be evaluated based on several key factors:

1. Precision: Laser CNC machines are known for their high precision. The beam emitted by the laser source is focused to a very fine point, allowing for precise cutting and engraving. The accuracy of the machine's movement, guided by the CNC control system, also contributes to its overall precision.

2. Speed: The speed at which a laser CNC machine can perform cutting and engraving operations is an important performance factor. Higher cutting speeds enable faster production, while engraving speeds determine the time required to create intricate designs. The machine's power output, motion control system, and material properties can affect the achievable cutting and engraving speeds.

3. Power and Capability: The power output of the laser source plays a crucial role in determining the machine's performance. Higher laser power allows for faster cutting and engraving speeds and the ability to process thicker and tougher materials. However, it's important to note that different materials have varying power requirements for optimal cutting and engraving results.

4. Material Compatibility: The range of materials a laser CNC machine can effectively cut and engrave is an important performance aspect. CO2 laser machines are typically capable of processing materials such as wood, acrylic, plastics, leather, fabric, paper, and certain metals. However, the compatibility may vary depending on the specific machine and its power output.

5. Software and Control System: The efficiency and user-friendliness of the machine's software and control system impact its overall performance. A well-designed software interface allows users to easily import, create, and modify designs, while a robust CNC control system ensures precise and accurate execution of those designs.

6. Maintenance and Reliability: The reliability and maintenance requirements of a laser CNC machine are crucial for its long-term performance. Regular maintenance, such as cleaning and aligning optics, replacing worn parts, and ensuring proper ventilation and cooling, helps maintain the machine's performance and extend its lifespan.

7. Safety Features: Laser CNC machines should incorporate adequate safety features to protect operators from potential hazards. These may include interlock systems, enclosed work areas, laser shielding, and safety protocols for handling and operating the machine.

It's important to note that the performance of a laser CNC machine can vary depending on factors such as the specific model, manufacturer, machine design, and user expertise. It is recommended to consult the machine's specifications and user reviews to evaluate its performance capabilities for specific applications and requirements.

1.4. WORKING PRINCIPLE OF LASER CNC MACHINE

This kerf completely enters the material close to the favored decreased shape. This strategy is a hit handiest if the mellow area infiltrates the workpiece. Laser metallic decreasing is therefore regularly restricted to thin portions. While decreasing has been accounted for through 100 mm segments of steel, the technique is more prominent for the most part utilized on metallic sheets 6 mm. or on the other hand substantially less in thickness.

The working principle of a laser CNC (Computer Numerical Control) machine involves the integration of laser technology and computer-controlled movements to perform various material processing tasks. Here is a general overview of the working principle:

1. Laser Generation: The laser CNC machine consists of a laser source, which is typically a high-powered laser such as a CO2 laser, fiber laser, or solid-state laser. The laser source produces a coherent and concentrated beam of light with a specific wavelength.

2. Beam Delivery System: The laser beam is directed through a beam delivery system, which typically consists of mirrors and lenses. The system controls the path and focus of the laser beam, guiding it to the desired location on the workpiece.

3. Workpiece Setup: The workpiece, which can be made of various materials such as metal, wood, plastic, or glass, is securely placed on the CNC machine's work surface. The workpiece may be fixed in place using clamps, fixtures, or a vacuum table, depending on the machine design and the application requirements.

4. CNC Control System: The CNC control system serves as the brain of the laser CNC machine. It consists of hardware and software components that coordinate the machine's movements and laser operations. The operator uses the CNC software to create a digital design or program that specifies the desired cutting, engraving, or marking patterns.

5. Material Processing: Once the CNC program is loaded and the parameters are set, the laser CNC machine initiates the material processing operation. The CNC control system sends commands to the machine's motors and actuators, which move the laser head and workpiece along predefined axes (typically X, Y, and Z axes).

6. Laser Operation: As the workpiece moves, the laser beam is precisely focused onto the material's surface. Depending on the desired operation, such

as cutting, engraving, or marking, the laser power and other parameters are adjusted accordingly. The focused laser beam rapidly heats and vaporizes or melts the material, creating the desired effect.

7. Cooling and Safety Measures: During laser operation, heat is generated, so laser CNC machines are equipped with cooling systems to dissipate the heat and maintain stable performance. Safety measures, such as enclosures, interlocks, and protective eyewear, are implemented to ensure operator safety and prevent accidental exposure to laser radiation.

8. Automation and Monitoring: Advanced laser CNC machines may incorporate automation features, such as automatic tool changers or robotic arms, to enhance productivity and versatility. Monitoring systems, including sensors and cameras, may be utilized to inspect the process, detect anomalies, and ensure accuracy.

9. Completion and Finishing: Once the programmed operation is complete, the machine stops, and the workpiece can be removed from the CNC machine. Further post-processing or finishing steps, such as cleaning, deburring, or surface treatment, may be required depending on the application and desired outcome.

The working principle of a laser CNC machine combines the precision and versatility of laser technology with the automated control capabilities of CNC systems, enabling a wide range of material processing applications with high accuracy and repeatability.

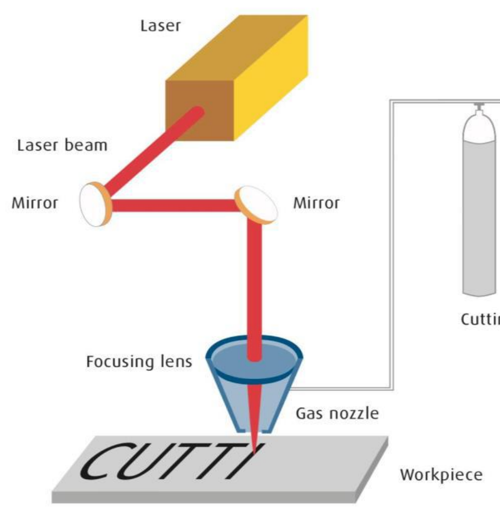

Figure-3: Working Principle of Laser CNC Machine

2.FACTOR AFFECTING THE PERFORMANCE OF LASER CNC MACHINE

The performance of a laser CNC machine can be influenced by several factors. Here are some key factors that can affect its performance:

1. Laser Power: The power output of the laser source significantly impacts the machine's performance. Higher laser power allows for faster cutting speeds and the ability to process thicker and tougher materials. However, the power requirement varies depending on the material being cut, as different materials have different absorption properties.

2. Material Type and Thickness: Different materials have varying properties and requirements for laser cutting. Factors such as material composition, density, and thickness can affect the cutting speed, power settings, and overall performance of the machine. Some materials may require additional considerations, such as the use of assist gases for efficient cutting.

3. Beam Quality: The quality of the laser beam, including its focus and beam profile, can affect the precision and quality of the cuts. A well-focused beam with a smooth profile produces cleaner and more accurate cuts. Beam quality can be influenced by factors like the laser resonator design, optical alignment, and beam delivery system.

4. CNC Control System: The CNC control system plays a crucial role in the performance of the machine. It determines the accuracy, speed, and repeatability of the machine's movements. A robust control system with precise motion control algorithms ensures accurate positioning and smooth motion, resulting in high-quality cuts.

5. Optics and Beam Delivery System: The quality and maintenance of the machine's optics, including lenses, mirrors, and beam delivery components, can affect the performance. Proper alignment, cleanliness, and calibration of these components are essential for maintaining beam quality and achieving optimal cutting results.

6. Software and Programming: The software used to operate the laser CNC machine and generate cutting instructions plays a significant role in its performance. User-friendly software with advanced features for design creation, nesting, and process optimization can enhance efficiency, speed, and productivity.

7. Maintenance and Calibration: Regular maintenance, including cleaning and aligning optics, replacing worn parts, and ensuring proper ventilation and cooling, is essential for optimal performance. Regular calibration of the machine's components, including the laser beam alignment, ensures consistent and accurate cuts over time.

8. Operator Skill and Training: The skill and training of the machine operator can affect the performance of the laser CNC machine. An experienced operator who understands the machine's capabilities, material properties, and programming techniques can optimize the cutting parameters and troubleshoot any issues that may arise during operation.

Considering these factors and ensuring proper maintenance and operational practices will contribute to the overall performance and efficiency of a laser CNC machine.

3. LITERATURE REVIEW

The section outline of the archive concentrated on the functioning system of CNC laser machines, plan, and activity of CNC machines.

Gadallah, Abdu [2015]: Beat Nd:YAG laser cutting of tempered steel (316L) improves kerf tightening and mean surface harshness. ends with that, Taguchi advancement findings reveal that 150W low-level power, 0.5MPa gas pressure, -125 Hz substantial heartbeat recurrence, and 0 cm cutting velocity/minute provide the highest draining quality. 150 W low-end power, 0.5 MPa gas pressure, 25 Hz beat repetition, and 20 cm/min cutting velocity are typical at equivalent surface discomfort. Over cycle boundaries, power and support gas pressures shape the kerf. Power, oxygen voltage appropriation, beat recurrence, cut-off rate, and tension division/oxygen recurrence cooperation affect Ta. However, power, oxygen pressure, beat recurrence, cutting velocity, oxygen tension cooperation, and cutting tempo affect Ra. The RSM models showed that S/N proportion values caused 21.1 and 2.86% mean percent variances in kerf tighten and surface unpleasantness, respectively. The response surface map shows that beat recurrence and cut-off rate affect Ta less than boundaries. However, Ra may be reduced at lower cycle boundaries without reducing velocity.

Ranjan et al [2015]: The usage of this software makes it possible to provide low-cost computerization for low-end applications of CNC technology that do not need an overly high degree of accuracy. These applications are often found in the automotive, aerospace, and manufacturing industries. These innovations are intended to make the procedure simpler while also elevating the degree of accuracy that may be achieved. Numerous more goods that are quite comparable (such as drills, processors, punchers, and so on) are able to be manufactured at a far lower cost of development, which puts them within the financial reach of small and medium-sized firms.

Jamaleswara et al [2018]: In light of recent advancements in the realm of practical application, laser cutting and etching equipment, which has a power of 500 mW and a frequency of 05 nm, has become more costly to acquire. As a result of the conclusions of a record survey and the phases of a work technique, the laser cutting and etching machine has been improved. You will need to be knowledgeable with the steps involved in the construction of a laser etching and cutting machine, which may be shown in the laboratory. As a consequence, the quality of the cutting and etching achieved is of the greatest standard imaginable.

Habsi, Rameshkumar [2016]: The selling price of 3 pivot small CNC machines has significantly increased over the last few years as a consequence of the growing demand for 3axix scaled-down CNC machines that can produce high-accuracy components in a variety of businesses. In the domain of assembly, small components should be supplied in an adaptive and effective manner in an assembly process in order to minimise overall costs that are fair for individuals and private businesses. CNC machines have achieved the highest possible level of accuracy and precision thanks to efficient body part determination as well as precise adjustment, testing, and assembly processes. This assignment involves the planning and production of a simple three-hub CNC machine at a cost of just 150 Omani Rials. During the period when the underlying model was being developed, a great deal of well-known CNC structures were discovered and evaluated. The support type structure that was selected and developed by a French person in England is the one that makes the most sense to build. To ensure that the requirements are satisfied, the fundamental components, such as liners, stepper engines, microcontrollers, and modules, are hand-picked from among an infinite number of available options. The ideal expenditure portions are selected so as to provide accuracy and straightforwardness while also satisfying the objectives of the financial plan. The accumulation of a mechanical component and its subsequent emergence as an electrical component is something that is eagerly awaited. In-house utilisation and the research facility are used to acquire data for the CNC machine model, which is then used to meet pre-gathered testing requirements for machine components. A CNC structure organisation was followed to meet precision while combining it into electrical and mechanical elements together, and the methods to produce a wooden design were continued thoroughly from that organisation. The design was then constructed. The procedures involved in setting up and aligning are broken down and shown in all of their granular detail. In order to ensure that the machine can be relied on, its complete capabilities have been validated by means of a variety of tests, ranging from programming validation to mechanical validation. In addition, the fundamental flaws that have been discovered and characterised have been discussed. machine.

Ji et al. [2017]: Present a one-time-elapse crackles laser cutting technology for Al2O3 earthenware manufacture. They can bend profiles. A break-free cut requires interaction limits like these: Cutting velocity should be 0.23–0.2 mm/s. When the laser head rotates at 3mm/s, boring duration should be 0.1-0.5 seconds, penetrating progress 0.03-0.05mm. Power should be 3500W and obligation cycle under 30%. These results suggest that break-free laser cutting may produce complex clay shapes. Black and Chua focused on CO2 laser cutting thick ceramic tiles from 8.5 mm to 9.2 mm . They sliced tiles at different velocities to determine cutting limits for tile computations. Reducing protective gas use was also examined. Multi-line cutting and submerged slicing were tested for managing heat load. The high-temperature slope in the substrate surface causes break damage when CO2 lasers cut burned tiles. Cycle actuated break development reduction is thought to be important for laser ceramic tile cutting in company. In another article, inexpensive earthenware tiles were cut using a CO2 laser shaper to provide a laser pillar machining (LBM) data set including boundary data for handling. Black et al. concluded. They focused on laser cutting limits that cut earthenware tiles without post-handling. They also consider protecting gases, cutting methods, and submerged cutting. Boundaries' effects have been shown. They created a model to study how state-of-the-art affects laser pillar retention. A quick multi-line cutting interaction may provide a "break free" cut with breaks limited to grain size. Collaboration time, radiation, and assistance gas tension affected quality result variables like periphery point, frequency, and distance. The connection time most affected the periphery's propensity, followed by supporting gas pressure and radiation. Communication time and radiation, which raise frequencies, also affect periphery frequency and length. They evaluated how normal power and assist gas pressure shaped the cut. The CO2 laser cuts shale well. CO2 laser slicing records are metal-like, too. Oxygen helped speed up the process. Finally, 1200 W laser power cut 13-mm tiles well. An engaged CO2 laser bar formed a straight boundary on the substrate surface, then an unfocused CO2 laser shaft illuminated the boundary to create pliable pressure and separate the substrate segments. They calculated the temperature appropriation and warm pressure field using ANSYS FEM programming. This two laser pillar structure may split the glass substrate in the desired direction and improve slicing quality compared to cutting with a single unfocused laser bar. Crouse et al. [8] examined CO2 and high-power diode laser test findings under similar exploratory conditions. Under similar testing settings, the multifocal diode laser infiltrates more than the CO2 laser.

Pushkal Badoniya [2018]: Laser cutting is undergoing extensive research to better understand the nature of the cut. The study reveals that the quality of the cut is determined by a wide range of control variables or boundaries, including those associated with the laser shaft (laser power, beat width, beat recurrence, methods of activity, beat energy, frequency, and central position), the material (type, optical and warm properties, thickness), the assist gas (type and strain), and the handling (cutting rate). Different quality characteristics, such as material expulsion rate (MRR), kerf quality attributes (kerf width, kerf deviation, and kerf tighten), surface quality (cut edge surface unpleasantness, surface morphology), metallurgical quality attributes (recast layer, heat impacted zone, oxide layer, and dross considerations), and mechanical properties (hardness, strength), have been studied in relation to these cycle boundaries.

N. Yusoff et al. [2019] focused on Malaysian light hardwood CO2 laser cutting. They determined optimal cutting conditions by establishing the relationship between handling limits and wood species with different qualities. They also provide cutting instructions for Malaysian woods. Since water absorbs CO2 laser light, dampness reduces cutting ability. Nitrogen, an idle gas, may also improve results. However, they advise that the approach must prove that the relevant expenses are not fixed before it can be used. Hattri considered carpentry lasers. He chose the CO2 laser because it was simpler to produce a higher energy thickness with wood than with the YAG laser. According to Barnekov et al. laser pillar quality, gadget and cycle variables, and workpiece attributes affect the laser's wood-cutting capabilities. Most wood-cutting lasers have 200–800 W. The appropriate cutting velocity and laser power depend on the workpiece thickness, thickness, and optimal kerf width for accuracy. If the cutting velocity is constant, cutting wet wood needs more power than cutting dry wood. They found the best centre point at the surface using laser power from 0 to 500 W and a cutting velocity of 20 in/min. They utilised 0.05-inch-spout pressurised air. They concluded that laser wood slicing warrants additional study. Both research examined the significance of LBC restrictions such laser power, cutting rate, spout architecture, and protective gas speed on safeguard type. found optimal MDF CO2 laser cutting settings. When cutting speed rose, kerf width decreased. MDF layout, which comprises covers, folios, tar, and so on, may also vary cutting rate. When the protective gas type or tension was altered, cutting width did not decrease. They also stated gas pressure did not improve Ra value. As cutting velocity increases, Ra rises. Finally, tension and gas expansion do not affect the worst shear rate for any thickness. Thus, compressed air laser cutting is more efficient than nitrogen. MDF. They developed a test equipment to detect severe power failures while laser cutting MDF in CW or beat mode. To control the horizontal stream, they altered the shaft's centre location and speed. Each board thickness and interaction boundary combination has a centre scenario. They could also use a histogram of the centre situation with the board thickness for the least edge kerf and a chart of cutting velocity vs. board thickness to establish ideal cutting circumstances.

Jayaprasad et al [2020]: The use of the CNC regulator has substantially contributed to improvements in product quality as well as high flexibility. It speeds up the process while simultaneously increasing the amount of efficiency gained. The combined effort of this piece of equipment with Gcode and Mode results in an increase in productivity and a reduction in responsibility. Gcode and Mode make it easy to locate the position data of all moving stepper engines. This is made possible by the fact that the state of our moving engine is shown clearly on the personal computer. The capacity to cut paper, polystyrene, and fragile sheets is made possible as a result of the construction of a small machine, which also increases flexibility in terms of carrying out the work opportunity and reduces the expenses associated with prototyping. The planning and production of this item will only cost a little bit of money. Taking everything into consideration, the task's goals of exactness and repeatability were successfully reached by the accuracy plan and manufacture of the CNC-based laser checking machine body come together.

Oktatian et al [2021]: When cutting acrylic with a CO2 CNC laser shaper, we commissioned a study to determine the optimal setup of cycle limits. Treatment time, layering accuracy, surface harshness, and fossil fuel byproducts were the four responses tested using the Taguchi multi-reaction technique. The SNR for each response was determined using Taguchi's method. The optimal placement of the interaction boundaries for each part of the trial was simultaneously determined using the GRA approach. To enable multi-objective improvement and determine the precise value of the ideal cycle boundaries, the response surface method (RSM) was used to determine the numerical model based on the trial results. jointly weaken the input at the same time. According to the results of the experiment, the optimal cycle limits are 65% laser power, mm/s cutting speed, and mm spout separation. While the RSM method's results suggest that 75% laser power, 5.9 mm/s cutting speed, and 3 mm spout dispersal are optimal cycle bounds.

4. CONCLUSION

Following is a summary of what was discovered after reviewing all of the research articles included in the literature review section:

the utilization of laser CNC machines for cutting different types of material sheets offers numerous advantages. The precision of laser cutting ensures intricate designs and fine details, resulting in clean and accurate cuts with minimal waste. The versatility of these machines allows for the processing of various materials, expanding their applications across different industries.

Laser CNC machines significantly improve efficiency by enabling faster cutting speeds compared to traditional methods. The non-contact nature of laser cutting minimizes material waste and eliminates the need for additional finishing processes. The clean and smooth cuts achieved through laser cutting reduce the need for post-processing, saving time and effort.

Moreover, laser CNC machines excel at cutting complex shapes and reproducing intricate designs, offering consistent and precise production capabilities. The automation and reproducibility features further enhance efficiency, making them suitable for mass production and repetitive cutting tasks.

Overall, the use of laser CNC machines for cutting material sheets provides a reliable and efficient solution that combines high precision, versatility, and automation. These machines have revolutionized the manufacturing and fabrication industries by enabling faster production, reducing waste, and delivering superior quality cuts.

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