FUTURE OF ROBOTIC LASER CUTTING IN THE INDUSTRY 4.0 ERA

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Article History: Received: 12.12.2022 **Revised:** 29.01.2023 **Accepted:** 15.03.2023

Abstract

Manufacturing is not possible without laser cutting, a non-contact thermal cutting method. Laser cutting is the first step in the manufacturing process for metal, followed by joining and manufacturing techniques like welding. Based on the development of technology and the digital revolution led by Industry 4.0, intelligent systems like automation and robots will be used in the future of metal production processes like laser cutting. Moreover, the use of energy-efficient materials is made possible by the digital transformation, where robots and automated systems are significant drivers. High-strength steels (HSS) for structural applications (such as bio-energy structures, wind turbines, and ice-going boats) on land, at sea, and in the Arctic are examples of such energy-efficient materials. This essay aims to clarify the potential of robot laser cutting systems within the context of integrated metal manufacturing in the factories of the future. On the basis of scientific and commercial viewpoints, previous investigations on laser cutting technologies are analysed. The well-known flat-bed laser cutting CNC machine is contrasted with the robot laser cutting system in a number of areas, including production flexibility, digitalization simplicity, off-line functionality, and investment analysis. The research will be used to compare robot laser cutting systems against flat-bed laser cutting CNC machines, especially when it comes to small and medium-sized businesses that manufacture metal (SMEs). The purpose of this study is to stimulate experimental and computational research on robot metal laser cutting systems and to assist businesses in selecting the laser cutting technology that will best serve their future manufacturing operations.

Keywords: Metals, Integrated Manufacturing, Robotics, Automation, Digitalization

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DOI: 10.31838/ecb/2023.12.s3.115

1. Initialization

The use of lasers to cut sheet metal parts was invented in the 1960s, and nowadays the technique may be used using CO2 lasers, fibre lasers, and diode lasers. The use of a laser cutter necessitates stability, accuracy, speed, and precision. For instance, in the automotive sector, highly developed automated robots use lasers to cut a range of materials, mostly stamped metal components, formed metal components, sheet metal blanks, etc. The robot laser cutting technology is not frequently used in most sectors, despite being widely used in the automobile industry. Ordinary robots focus on tasks that call for little accuracy, which is one of the causes. Moreover, due to inadequate axis control skills or overloaded axes that are inappropriate for targets moving quickly, standard robots are less effective. Ordinary robots are also thought to be lightweight and lacking in stiffness, which causes instability and shaking issues (Tian et al., 2017). These factors have led to the acceptance and widespread use of linear axis flat-bed laser cutting CNC machines for the fabrication of metal sheets, tubes, and plates. A flat-bed laser cutting CNC machine is used to accomplish 90% to 95% of laser cutting operations; 3D laser cutting heads are seldom ever used for cutting 3D forms and patterns.

Yet, the present industrial revolution, which is fueled by Industry 4.0, encourages the fusion of production processes with cutting-edge technology centred on automation and robots. This implies that companies using laser cutting methods will not be an exception to factories incorporating greater automation and robotic technology in the future. Robot laser cutting systems may therefore be included into manufacturing processes in sectors other than the automobile industry. The International Federation of Robotics predicts that by 2020 there will be over 3 million industrial robots in use globally (Gyasi et al., 2022), with metal manufacturing being one of the primary sectors where robots will be installed. These findings highlight the urgent need to research the potential for robot laser cutting in integrated metal production companies. The many factors examined in this article are depicted in Figure 1. Initially, studies were conducted on the various laser types and their use, particularly in integrated metal production companies. The second factor taken into consideration for comparisons was the arrangement of the equipment, which in this case included a flat-bed laser cutting CNC machine and robot laser cutting systems. Studying robot laser cutting systems in the era of Industry 4.0 involved looking at a number of elements, such as flexibility and adaptability, digitization ease, and offline cutting capabilities. Eventually, it was decided that a discussion on investment strategies for the two sets of machinery and equipment was essential.

2. Integrated Manufacturing with Laser Cutting

The most significant application in materials processing today, in terms of market share, is laser cutting (Demianova, 2018). When components and patterns are cut from sheet metal, metal plates, or metal tubes for the manufacture of high or low volume goods to service a variety of industries, laser cutting is at the top of the production chain. With a cutting precision and accuracy of around 0, 05 mm and very little heat impacts on the cut items, laser cutting is a high-speed computer numeric control (CNC) technique. Aluminum, stainless steel, and mild steel are typical metals used for laser cutting. Metals' physical qualities, particularly their thickness, surface reflectiveness, chemical composition, and mechanical capabilities, must be taken into account when using a laser to cut them. The thickness range for mild steel and stainless steel that is acceptable for laser cutting is between 0.5 and 20 mm, whereas the thickness range for aluminium is between 0.5 and 8 mm (Salahuddin & Lee, 2022; Sun et al., 2015).

Examining a number of factors connected to the laser system, materials, and process is necessary when choosing between a flat-bed laser cutting CNC machine and a robot laser cutting system. While they cannot be changed by an operator, the laser system's critical characteristics include maximum output laser power, laser beam quality, and laser radiation wavelength. An operator can change the settings for the materials and the processes. The processing parameters are the laser power, cutting speed, focal length of the focusing lens, focal point position in relation to workpiece top surface, type and pressure of assist gas, gas nozzle diameter, and gas nozzle stand-off distance. The material parameters are the thickness and type of the material. The many laser types are worthwhile discussing, though, as the laser system is sensitive when treating materials. The CO2 laser, Fibre laser, disc laser, and diode laser are among the different laser types frequently used in the processing of metals. This is an explanation of the many types of lasers and how they differ and are similar in functioning.

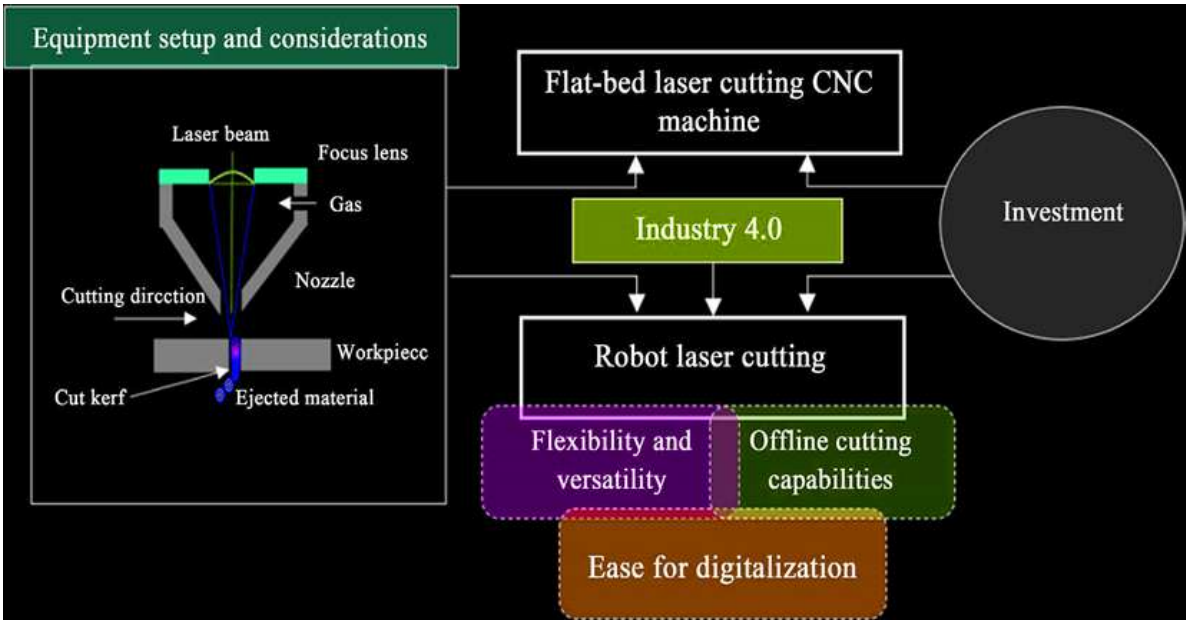

Figure 1: Schematic framework highlighting important factors in laser cutting, particularly when investigating robot laser cutting in the era of Industry 4.0

2.1. Types of Laser

The most widely used type of laser is the carbon dioxide laser (CO2 laser). With a CO2 laser, a gas combination consisting of 78% helium, 12% nitrogen, and 10% carbon dioxide produces laser light. The CO2 laser generally operates at a wavelength of 10.6 m and requires up to 100 kW of power (Livesey, 2018). Due to the high rate of laser beam absorption (Wandera, 2010) and good beam quality at high output levels sufficient for cutting thick-metal sections, the CO2 laser is effective for cutting steels. Currently, steel plates with a thickness more than 5 mm are mostly cut using CO2 lasers. For cutting thicker plates, CO2 has superior cutting quality than fibre laser and operates more quickly. The CO2 laser is highly suited for cutting non-metallic materials such various plastics, glass, cloth, paper, and wood even though it is typically used to cut steel, stainless steel, or aluminium (Steen et al., 2008). The wavelength of CO2 lasers is absorbed by optical fibres, making it impossible to convey the laser beam using fibre technology.

Fiber Laser: The laser beam is directly shaped into the optical fibre and transferred to the machine's cutting head using the same medium. The light source is a diode laser, while the medium and resonator are the fibre itself. The fibre laser is made up of a number of smaller modules, and it generates a powerful laser beam by combining the lasers that are created inside the fibre. Compared to CO2 lasers, fibre lasers are considerably smaller and produce twice as much power. Up to six or seven times as efficient, CO2 lasers are less efficient than fibre lasers. The fibre laser's wavelength, which is generally 1070 nm, makes it excellent for cutting reflective materials like copper or aluminium. As the beam is generated in a fibre resonator and does not need to be sent separately to the fibre, a fibre laser's excellent beam quality is its primary benefit (Kulakowski & d'Humières, 2022).

Diode Laser: Compared to fibre and CO2 lasers, diode lasers produce a lower-quality laser beam, making them less frequently used in metal laser cutting applications. A low-power diode laser that is packed together produces the diode laser beam. The diode laser's wavelength is around 970 nm, which is likewise less than the fibre laser's. Also, just like a fibre laser, the laser beam is sent to the target using an optical fibre. While the diode laser is more effectively absorbed by reflective materials like aluminium than a fibre laser is, its use is uncommon in the metal sector (Vuori, 2018). Due to difficulties merging several laser beams generated by low-power diode modules, the diode laser's most notable flaw is the beam quality. The beams must have distinct wavelengths in order to be combined. The diode laser has potential and is anticipated to one day be a completely competitive substitute for CO2 and fibre lasers.

Some laser types, such as the 1000 nm-wavelength solid-state neodymium-doped yttrium aluminium garnet (Nd: YAG) laser, are less reflective and absorb more energy in most materials (Larcombe, 2013). Nd:YAG laser technology is widely used in thin-section, high-precision metal cutting and transmits laser light through fiber-optic cable (Kellens et al., 2014). Figure 2 displays a schematic of a laser cutting front and potential outcomes. The cut edge surface roughness is visible as striations on the cut edge (Villarreal et al., 2016) due to the dynamic behaviour of the laser cutting process, which influences the form of the cutting front and the melt flow mechanism (see Figure 2(b)). Dross attachment is a different occurrence that occurs when some of the molten metal that is not entirely blown off from the laser cut kerf re-solidifies and attaches securely to the lower cut edge (see Figure 2(c)) (Mahamood & Akinlabi, 2018). Dross attachment is more likely to occur with metals that have higher surface tension and viscosity values.

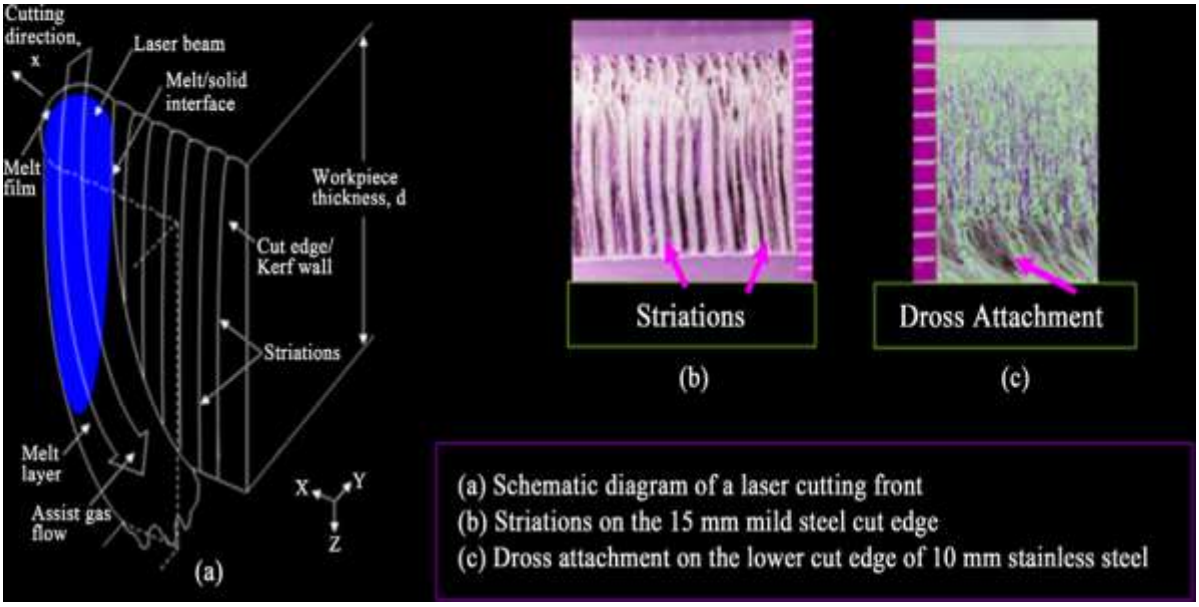

Figure 2: Examples of a laser cutting front, a mild steel cut edge with striations, and a dross attachment. altered figures (Horak et al., 2015)

2.2. A manufacturing with Integrated process

Both internal and external subcontracted services are available for laser cutting. Several big businesses and SMEs produce their own components utilising internal cutting equipment. Others would rather concentrate on their primary area of manufacturing expertise, such as welding, and outsource the laser cutting task to SMEs with relevant expertise. Due to the varied client base they serve, SME's that solely provide laser cutting as a subcontracted service occasionally experience high-mix, low-volume laser cutting manufacturing. Like this, certain SMEs who carry out their own product manufacturing and laser cutting are subject to high-mix low-volume production. The idea of integrated production is shown by these circumstances.

In this context, the idea of integrated manufacturing refers to a scenario in which many manufacturing processes are executed in a plant in small batches, sequentially, at various times. Materials handling comes first in the production process, as seen in Figure 3. Materials that need to be cut are transported for laser cutting and handled for either welding or bending and rolling, depending on which comes first. After handling for sandblasting, where the cut components are cleaned, the parts or components are then ready for use. After being sandblasted, the components are painted and sent to the department handling the completed product. A straight transition from one manufacturing process to another is shown by a solid line. An indirect series of operations is shown by the broken line. Therefore, after being laser cut, a part may be transferred to sand blasting, then to bending and rolling, where it may then be polished or it may be moved from bending and rolling to welding, sand blasting, or coating before the finishing process.

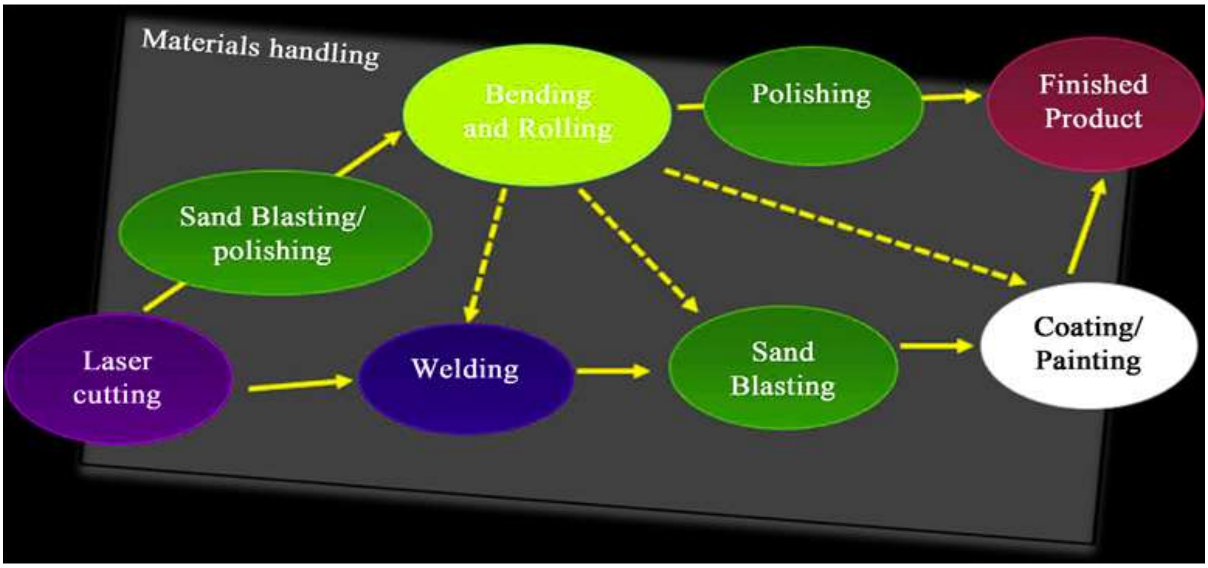

Figure 3: An example of integrated production at a facility that makes metal goods.

In order to complete these jobs with some amount of support from people, not fewer than 10 pieces of machinery and equipment are needed, considering the various production processes. Considering the factory's manufacturing cycle, time spent handling materials may have an impact on productivity and efficiency. However, by utilising automation, a small number of robots could be installed to carry out such dispersed manufacturing processes with little human collaboration in order to drive efficiency, productivity, and consistent material flow in the factory. This would result in a decrease in the number of machines in the factory and more ergonomically sound workspace.

In an integrated production facility, the use of automated systems and robot laser cutting might reduce costs, offsetting the high cost of flat-bed laser cutting CNC machines. Also, taking use of digitization in the internet of things (IoT) era and creating new, financially sound business models that benefit laser cutting enterprises are significant. In both cases, investment techniques must be looked at. However, when choosing laser equipment for cutting a variety of materials, such as flat-bed laser cutting CNC machines or robot laser cutters, it is important to carefully analyse the laser types, assist gases, regular production processes in the factory, business strategy, and investment.

3. Setup of the Equipment

3.1. Flat-Bed CNC Laser Cutting Machine

Figure 4 depicts a typical flat-bed laser cutting CNC machine. These kinds of laser devices require a vast area due to their bulkiness. The whole machine's dimensions, which consider its length, breadth, and height, might be in the range of 13,050 mm to 2450 mm. For nominal sheet sizes of 4000 x 2000 mm, the cutting area is approximately 4064 x 2032 x 70 mm. Due to its stiffness and X, Y, and Z coordinates, the machine's CNC mechanism enables positioning accuracy of 0.1 mm, repeatability of 0.05 mm, and high precision. It is possible to add 3D laser cutting heads to these devices to help with the cutting of intricate designs and components. Such devices typically use CO2 or fibre laser technology, with laser powers ranging from 4.4 to 10.0 kW (Horak et al., 2015). The flat-bed laser cutting CNC machine appears to be the market favourite and is present in major corporations and SME workshops throughout the world in 90% to 95% of cases. In the international market, the most well-known producers of laser cutting machines are Trumpf, Bystronic, Amada, Prima Power, Mazak, Bodor, Salvagnini, Han's Laser, Tanaka, and Koike, among others.

3.2. Robot Laser Cutting Systems

Robot laser cutting systems are basic automated laser technologies with cutting heads that rely on the dexterity of the robot end effector and the kinematics of the robot manipulator. A servo-controlled mechanism, a multi-axis mechanical manipulator, and a laser cutting head affixed to the robot's end effector make up a robot laser cutting system. A list of the traits of robot manipulators is included in Table 1. The cutting head generally functions as a height control device and features laser beam focusing optics. An assist gas delivery package delivers oxygen or nitrogen to the cutting head cable, depending on the type of laser technology being used.

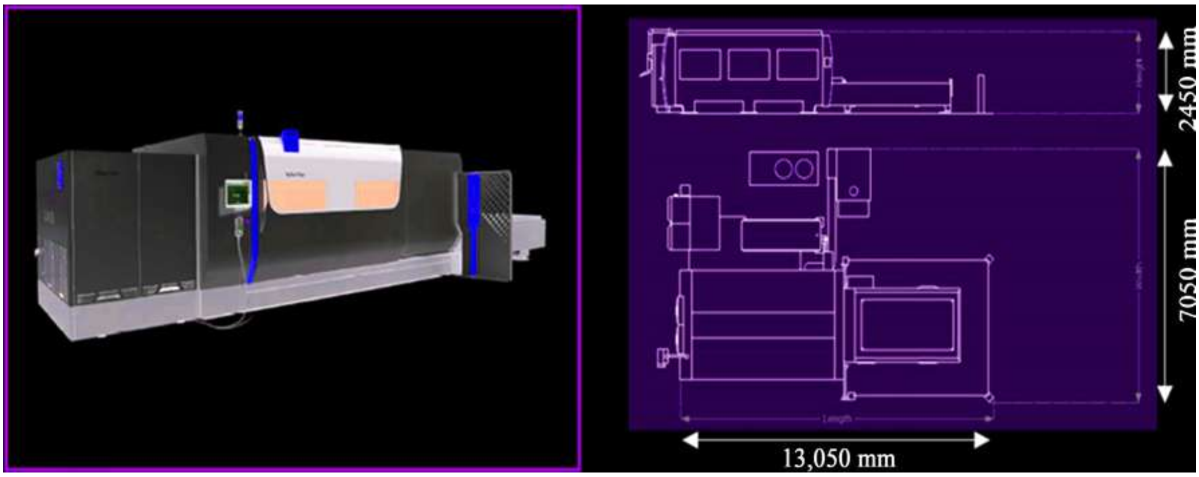

Figure 4: A flat-bed CNC machine for laser cutting in two dimensions (BySprint Pro 4020) (Livesey, 2018)

Table 1: Features of robot manipulators

Characteristics	Description
Repeatability	Up to 0.03 mm (0.1 mm is common)
Velocity	Up to 5 m/s
Acceleration	Up to 25 m/s
Payload	From around 2 - 3 kg up to ≈750 kg
Weight/Payload	Around 30 - 40
Axis	6 degree of freedom (3 translational and 3 rotational)
Communication	Profibus, Canbus, Devicent, Ethernet and serial channels (RS232 and RS485)

For laser cutting operations, robot manipulators can be installed in a variety of ways. The robot manipulator, for instance, can be installed on a wall, the factory floor, or in a gantry position. A typical illustration of a robot laser cutting system deployed on the manufacturing floor is shown in Figure 5(a). The robot laser cutting system may either be fixed or mobile on rails with this kind of setup. A mobile cutting bed with an automated system may be used while stationary. On the other hand, a stationary or mobile cutting bed with an automated machine might be used if the robot laser cutting system is mobile on tracks. The other types are gantry or overhead positions, as seen in Figures 5(b)–(e), where the robot manipulator is positioned on crane-like frameworks above the manufacturing floor (d). Due to the reachability of the manipulator and rotating motion of the end effector, gantry robot systems behave like Cartesian or linear robots, where movement happens in the horizontal plane (i.e., from left to right or front and back) and in the Y and Z plane. These gantry robot capabilities improve the reach, speed, and precision of the laser cutting head's agility for challenging operations.

The benefits of using robots in laser cutting processes are compelling in today's era of industry 4.0. Basically, Industry 4.0 envisions the conversion of conventional industrial manufacturing into smart manufacturing where the manufacturing systems are able to: 1) digitally monitor physical processes and make adaptive intelligent decisions through real-time connectivity, collaboration, and communication with humans, machines, and sensors; and 2) adjust their behaviour. Industry 4.0 places a strong emphasis on automation, robotics, big data acquisition, big data fusion, and big data analytics. As a result, the use of robot automated systems augments the principles behind the Industry 4.0 idea. Robotic laser cutting systems are therefore interesting to investigate, especially in light of their adaptability and flexibility, simplicity of digitization, and ability to do off-line laser cutting operations.

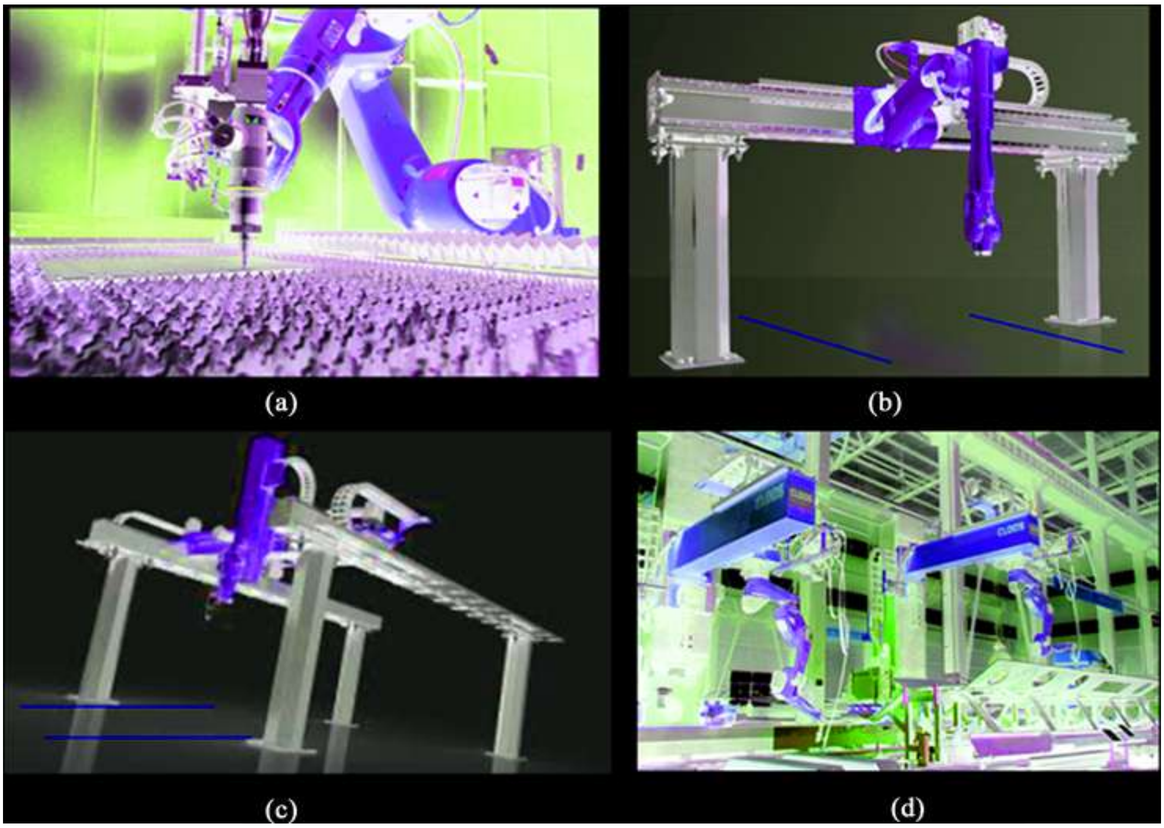

Figure 5 shows several different robot configurations for performing laser cutting operations: (a) a floor-mounted robot laser cutting system; (b) a gantry-mounted robot laser cutting system that operates in the X-Y-Z plane; (c) a gantry-mounted Cartesian robot laser cutting system that operates in the X-Y-Z plane; and (d) a gantry-mounted linear robot laser cutting system that operates in the X-Y-Z plane.

3.2.1. Versatility and Flexibility

Comparing robot laser cutting systems to flat-bed laser cutting CNC machines, robot laser cutting systems have more flexibility and adaptability. According to test results, robot laser cutting is flexible and versatile, especially as a technology that has the potential to completely transform the laser cutting market. For a very large working area, a robot laser cutting system might be positioned on the manufacturing floor or in a gantry position. Robot laser cutting is becoming more and more used in the automobile sector because of its adaptability. Robotic laser cutting systems, however, might be used for various purposes, such as the production of pressure vessels. For the purpose of creating circular patterns and forms on sheet metal for pressure vessel manufacture, the metal can be bent first, and then the patterns or circles can be cut from the top, bottom, or sides. Circular forms are often cut from sheet metal and then bent when creating pressure vessels, as is the standard. The difficulty in this situation is that the circular shapes after bending became elliptical, necessitating further manual cutting and grinding procedures. This has an impact on the precision of the shapes, the productivity of the labour, and the economies of scale.

The robot laser cutting system also has the capacity to cut complicated geometries and 3D objects from sheet metals, stamped metal blanks, formed metal components, tubes, and metal plates. Robotic laser cutting systems can handle bespoke goods in high-mix, low-volume or low-mix, high-volume manufacturing environments and can react to variations and changes in manufacturing needs. Robot laser cutting systems may do various industrial jobs when the laser system is decoupled due to its adaptability and integration capabilities. A common example is the integrated production framework (Figure 3), which allows at least one robot to be reused and utilised interchangeably to complete the majority of the manufacturing procedure. It has been stated that the low cost of robot laser cutting equipment is spawning new enterprises in the automobile sector. According to the survey, 3D laser-cutting robotic solutions are becoming the top option for many laser-cutting applications, including those for passenger car bodywork, agricultural machinery, electric automobiles, and automotive spare parts. In a similar vein, it has been claimed that robot laser cutting has a return on investment of less than two years, and that when a robot laser cutting system is put in place, it is possible to do away with multiple workstation machines and equipment, opening up opportunities for the same robot to be used in other manufacturing tasks (Livesey, 2018). Robot laser cutting has received some positive press, particularly from companies like KUKA, ABB, FANUC, YASKAWA, STUBLI, and KAWASAKI. Robot laser cutting systems are characterised by these benefits in these success stories: reduced energy consumption, lower maintenance requirements, small batch processing, quick cutting speeds, shortened production cycle, small kerf, smooth cutting edge at 3D surface, reduced pollution in production, improved human collaboration, no tool wear, long service life, high reliability and stability for mass production and processing requirements.

3.2.2. Digitalization is Simple

Robot laser cutting systems are flexible enough to allow sensors and monitoring equipment to be connected to the robot manipulator, end effector, or laser cutting head. By online process monitoring approaches (pre-process, in-situ, and post-process monitoring), as well as by modelling and controlling using artificial intelligence (AI) techniques, laser cutting activities may be seen and forecasted. Artificial neural networks (ANN), fuzzy logic, neural-fuzzy networks, adaptive neuro-fuzzy inference systems (ANFIS), genetic algorithms (GA), and particle swarm optimization (PSO) algorithm are some of the AI techniques used today. The ANN is frequently used for modelling and control of uncommon events in the field of robotic welding and may also be used in the field of robot laser cutting. (Wandera, 2010)Provides comprehensive scientific details on the introduction of neural network modelling and control techniques for rear events.

Practically speaking, the ANN depends on input and output data, such as experimental data, and this data serves as the foundation for identifying the structure and parameters of the model. When ANN is implemented, data retrieval and collection for modelling and simulation purposes are guaranteed. A straightforward ANN architecture may be created, as shown in Figure 6, to model and regulate the input and output data while taking into account laser cutting and the associated parameters. When quality, accuracy, and precision cuts are required during robot laser cutting operations, the ANN architectural arrangement is used to maximise prediction and control. The back propagation (BP), resilient propagation (RPROP), Levenberg-Marquardt, genetic algorithm (GA), and particle swarm optimization (PSO) learning algorithms are some of the learning methods used by the ANN architecture. Typically, sum biassing is used to weight the input data, which is then processed via an activation function to create the output. Each process's result is compared to the desired output, and the discrepancy between the two generates an error signal. By re-presenting the error to the neural network system in a way that will reduce the error for each iteration, the weight is modified. This method seeks to lower the error value while bringing the neural network system model closer to the intended outcome. The chosen learning algorithm modifies the weights as the number of iterations rises, lowering the error and bringing the resultant target closer.

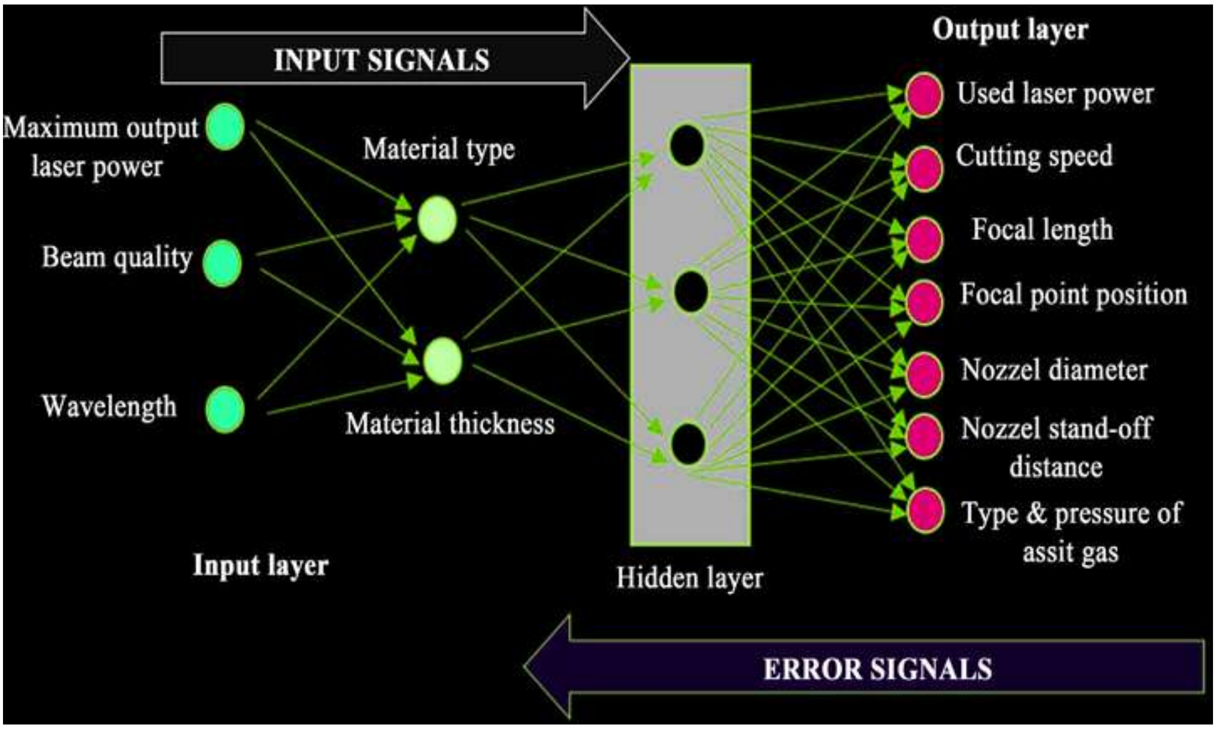

Figure 6: A potential ANN design for parameter modelling and control in robot laser cutting.

Benefits of adopting robot laser cutting systems include the potential for real-time digital monitoring of the physical process. Robot laser cutting systems can also benefit from nesting and anticipating the best cutting sequences to prevent material deformation, viewing the whole process, and removing severe heat-affected zones (HAZ) that could impact the characteristics of the material before and after cutting.

3.2.3. Off-line Robot Laser Cutting

To support robot laser cutting of sheet metal, tubes, stamped-metal plates, etc., 3D simulation software has been developed. This innovation significantly advances metal cutting's transition to Industry 4.0 by digitally revolutionising the laser cutting sector. In order to enable operations in both virtual and real-time modes, a simulation model (virtual twin/digital twin) of the actual robot laser cutting system is constructed. By simulating the robot laser cutting process, it is possible to reduce the amount of time spent online programming while also minimising the likelihood of malfunctions or workplace accidents. This reduces the need to experiment with cutting effects in real-time and increases productivity. As a result, robot laser cutting programmes are created offline and made operational in real-time. Measurements, calibration, verification, and validation of the cut sites and targets are all part of the setup. Off-line laser cutting software, according to research, aids in modelling the impact and transport of heat in metal cutting, revealing how the heat is dispersed in the material and possibly influencing temperature on material characteristics. During the layout phase, the software tools also enable the selection of the best patterns and cutting orders while predicting and spotting any potential unanticipated abnormalities. It is possible to adjust the laser cutting operation's cutting trajectory and direction to retain excellent quality, accuracy, consistency, and precision. For robot laser cutting operations, commercially available software options include Vicomtech's and Lantek's BeroSIM and ALMA CAM.

Investment Evaluation

In the field of laser cutting, where automation and robots continue to be the driving forces behind contemporary manufacturing and production, investing in smart technology is essential. More expenditures are undoubtedly necessary in order to provide improved technical solutions. One must decide whether to invest in automated robot laser cutting systems with adaptive features, which are comparably less expensive (200,000 €), or flat-bed laser cutting CNC machines with complex features, which are typically expensive (>500,000 €). What is the profitability of the investment can be answered by paying close attention to automation and robotics, although this is debatable. When it comes to automation and robotics, a number of financial calculations are performed to determine the profitability of investments. Holamo suggested using the formula for net present value (NPV), which is written as follows:

$$\mathrm{NVP(i)} = \sum_{t=1}^{N} \frac{R_t}{(1+t)^t} + \frac{RV}{(1+i)^N} - C_0$$

where NPV(i) is the discounted value of the investment, t is the time period (in years), N is the total number of periods (i.e., the depreciation time), I is the internal rate of return target set by the company, Rt is the cash flow during period t, RV is the residual value at the end of the depreciation time, and C0 is the total cost of the initial investment. The investment is typically successful if, under the stated constraints for N and I the output NPV I > 0, and NPV computations are helpful when contrasting various types of investments with one another. The investment with the largest NPV value will be the one that is most lucrative. But, using a SME facility with high-mix, low-volume manufacturing in mind, this method might be used to assess the profitability of buying flat-bed laser cutting CNC machines vs robot laser cutting systems for cutting a range of materials, shapes, and thicknesses. From a strategic standpoint, investments in automation and robotics should be taken into account when developing new business models, selecting new target markets, and putting other futuristic manufacturing concepts into practise.

4. Discussion

Particularly in the metal sector, where a number of processes must be carried out in a smooth manner to complete the final product, manufacturing has become highly integrated. In this era of intelligent manufacturing, it is crucial to take into account machinery and equipment that is adaptable, flexible, and simple to integrate with smart technologies, particularly when taking into account SMEs that engage in high-mix, low-volume manufacture. The flat-bed CNC machine has had a dominant position in laser cutting to this day. For 2D sheet metal blanks, it may be approximated that 90% to 95% of laser cutting operations are carried out using flat-bed laser cutting CNC machines. On occasion, flat-bed CNC machines are equipped with 3D laser cutting heads for cutting three-dimensional items. Nevertheless, stamping, drawing, or even flat-shaped materials may be effectively and efficiently sliced using robot laser cutting. Robotic laser cutting is therefore primarily and unapologetically used in the automobile sector. Robotic laser cutting systems have certain benefits over flat-bed CNC laser cutting equipment, such as: Flexibility and adaptability; ease of digitalization; offline laser cutting; low investment cost; suitability for integrated production; high workshop space utilisation; easy deployment in emerging markets; and ability to monitor operations using AI and IoT.

From an industrial perspective, certain businesses in different industrial sectors continue to cling to the outdated notion that robot laser cutting systems cannot operate as productively as flat-bed laser cutting CNC machines. The fact that standard robots often concentrate on tasks requiring poor accuracy is one of the main reasons why robot laser cutting systems have not been extensively adopted. A 5 mm diameter circle is challenging to carve, and the final form seems oval. Second, these common robots are less effective because they lack the ability to manipulate their axes or have axes that are overloaded and ineffective against moving objects. Ordinary robots are also thought to be lightweight and lacking in stiffness, which causes instability and shaking issues. Also, it has been established that the mechanical setup used to move the workpiece and the laser limits cutting speed for typical robots rather than the laser's intensity. Such justifications are without a doubt obsolete, and I say this without prejudice. It is debatable whether contemporary robots are outfitted with effective axes control systems for accurate, efficient, and precise positioning and trajectory movement, despite the fact that it could be argued that the majority of robot laser cutting system integrators lack sufficient experience with the laser cutting process and have conducted little research in robot motion control, as noted by (Kulakowski & d'Humières, 2022). In spite of this, robot laser cutting systems may be programmed and operated to get beyond the limits that were previously present with regular robots thanks to modelling and simulation capabilities.

Because there are so many deployable automated configurations available today, such as the gantry position, robot laser cutting systems appear to be reliable. Also, the usefulness of robots is increasing in value in factories of the future where automation and digitization are still important worldwide industrial instruments. In contrast to the automobile industry, which has a 90% record, Gerrit Gerritsen noted that automation has not yet advanced effectively in the sheet metal sector, with 20% automated systems. Gerritsen stressed that employing robots up until this point had not been beneficial. This is so that a sheet metal production business utilising a robot may efficiently and productively make 1000 equipment brackets and other small series of goods throughout the day. By processing sheet metal, it is therefore feasible to accommodate both high-mix, low-volume manufacturing as well as low-mix, high-volume production, such as when a car manufacturer produces the identical chassis 100,000 times.

The choice of equipment depends on investment, and investment research is important in any organisation, but it's more important when intending to buy new machines to replace outdated equipment with a proven track record. Yet, it is necessary to follow changing industry trends, which involves a number of considerations for new technologies, expanding factory operations into untapped or developing markets like Africa, energy efficiency and environmental issues, etc. Ultimately, a direct comparison between robot laser cutting systems and flat-bed laser cutting CNC machines can be established in terms of energy efficiency and sustainability. Robot laser cutting systems hold the promise of being powered by renewable energy sources (such as wind or solar power) and adjusting power sources to match laser cutting systems in order to analyse and monitor their environmental footprints. In this regard, further research must be done.

5. Conclusion

In this paper, the potential of a robot laser cutting system has been investigated. In addition to comparing and taking into account many aspects of the equipment set up with flat-bed laser cutting CNC machines, concerns of intelligent integrated manufacturing and investment were also taken into account. The factors of automation and digitalization are the primary factors that move the focus from flat-bed laser cutting CNC machines to robot laser cutting systems for the sheet metal sector and other prospective metal work industries where energy-efficient materials are employed. Robot laser cutting systems can be said to be significantly more adaptable and versatile in terms of operations, easily integrating with intelligent sensing and monitoring devices for modelling and simulation, and capable of delivering offline laser cutting functionalities that increase productivity and profitability. Despite the significant expenditures required, flat-bed laser cutting CNC machines continue to have a dominant position in the industry. Yet, robot laser cutting systems demonstrate resilience in new factories. Also, the operational view and system integration of the robot laser cutting system appear to be cost-effective and offer sustainable solutions, particularly for SMEs that are known to run high-mix, low-volume manufacturing and production systems. Finally, the robot laser cutting systems remain a potential source of equipment for future laser cutting operations in diverse industries, being the sheet metal industry, automotive industry and other sectors. Hence, its potential to spearhead digitalization and automation in laser operations cannot be underestimated. Experimental and computational research, as well as further literature works, need to be conducted to advance the research in robot laser cutting of metals.

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