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# ANALYSIS OF THE LASER CUTTING PROCESS FOR A SELECTED COMPONENT

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***Abstract:*** The advancements in modern manufacturing technologies have made it possible to create customized, distinctive, and personalized products in single quantities or small batches tailored to the individual needs of customers, a process commonly referred to as "customization." However, this has introduced challenges in effectively planning production activities and manufacturing customized products, as it requires balancing customer demands with manufacturing capabilities. In addition to traditional production methods such as turning and milling, innovative techniques like laser cutting-particularly when coupled with a robotic arm-offer enhanced flexibility for producing specialized custom products and intricate patterns. This ability has contributed to laser cutting's rise as a competitive and widely supported method in modern manufacturing. A significant challenge in this domain is the dynamic nature of task execution in manufacturing, which can render cutting lines obsolete and often requires modifications at short intervals. These changes are driven by factors such as evolving customer requirements, shifts in materials, and new production orders. As a result, it is crucial to continually assess and implement the necessary adjustments to maintain process efficiency and ensure the smooth execution of planned activities. This article explores the application of laser cutting on various materials, such as tulle, and presents the results obtained. The objective was to develop a cutting technology suitable for manufacturing specific types of ion membranes that meet required quality standards and chemical purity levels. Additionally, an analysis using an Ishikawa diagram was conducted to identify areas for improving the quality of the cutting elements.
***Key words:*** laser cutting, production organization, automation, robotization, Ishikawa diagram.

## 1. INTRODUCTION

The need to make products in a short time, but also the solutions that are currently available, allow for the production of non-standard, personalized products in individual quantities and small series. This has caused a greater challenge for manufacturers to properly plan and produce products that are "tailor-made". The production of such products requires appropriate preparation both in the area of planning, but also in the area of execution, because it requires the coordination of many activities for individual products, changing variants. And thanks to the possibility of using new technologies and improving existing solutions, the implementation of the required activities becomes possible, and this also increases the possibility of executing subsequent orders [10,17]. The problems that appear in these areas concern aspects related to the economics of the solutions used, but also the possibilities of their implementation, but also the effects of the solutions used. In addition to welding, surfacing, additive manufacturing, modeling and simulation, cutting with various methods, laser cutting is also a very popular technology. The use of laser cutting technology supports manufacturers in the production of specific products and is the subject of many studies around the world [7].
The contrast between thermal laser cutting and mechanical vector cutting of thin material plates is a central theme in numerous studies within this field. As laser technology for material processing continues to advance, it is poised to replace many conventional techniques. Laser cutting can produce a wide array of profiles and shapes, including H beams, I beams, T beams, pipes of various diameters, HSS squares, HSS rectangles, angles, C channels, bulb flats, and flat sheets. This versatility allows for the effective use of both sheets and bars [4]. With the rapidly growing demand for metal cutting, there is a pressing need to develop advanced cutting technologies that enhance precision and cost-effectiveness. The most prevalent methods include laser cutting, plasma cutting, water jet cutting, and oxy-fuel cutting. Compared to other technologies, laser cutting offers superior precision, accuracy, and customization, making it particularly valuable for applications such as the dismantling of nuclear facilities. A laser cutting machine is an automated system that includes an industrial control computer, servo motor control, computer numerical control (CNC), and optical sensors. It primarily consists of mechanical and electrical control components. Laser cutting equipment is categorized based on its

light source, power, and dimensions. Various laser cutting technologies include vaporization, fusion, and reactive melting cutting. However, it is important to note that the cutting process generates dust, smoke, and aerosols, which raise environmental concerns and pose health risks to operators [16].

The reviewed studies indicate that the heat-affected zone (HAZ) of laser-cut materials increases with higher laser power and decreases with increased cutting speed [12]. This phenomenon occurs because greater power leads to more energy being absorbed by the material, while a reduced feed rate allows for more prolonged exposure to the laser. Furthermore, it has been demonstrated that the HAZ significantly diminishes the bending and compressive strength of composites, as this region cannot adequately support loads due to the exposure of fibers [13]. Additionally, fiber ablation generates gas pressure within carbon fiber reinforced polymers (CFRPs), causing the fibers on the upper surface to protrude. This results in a wider gap on the upper surface compared to the lower surface. Such gas pressure can also lead to cracks and delamination in the sample, which is unacceptable for structural components [13]. Multi-pass cutting has been shown to reduce the HAZ by allowing for cooling between passes. The implementation of dynamic beam shaping during laser cutting offers the opportunity for CFRPs to cool between laser interactions while maintaining a continuous process. This approach enables higher feed rates with minimal heat-affected zones [11]. The literature highlights that laser cutting is a non-contact process, which eliminates tool wear and cutting force, and enables cutting at sharp angles with a narrower kerf width. Additionally, lasers can transmit a beam of light through optical fibers, allowing for robotic manipulation of work heads and facilitating automation. However, a key challenge in laser processing is to minimize thermal damage while maintaining high cutting speeds. Issues such as a large heat-affected zone, carbonization, resin recession, and delamination represent significant quality defects that hinder the industrial application of laser processing for composites and plastics [3]. It is essential to note that the laser cutting process offers numerous advantages over traditional cutting methods, such as turning, milling, and drilling. These benefits include superior cutting quality, reduced material loss during the cutting process, and enhanced accuracy of the cut surface [1]. One of the contemporary challenges in the field is to establish a systematic approach for the design and construction of laser cutting machine prototypes. This process should encompass various stages, including calculation, design, simulation, and production. Additionally, it is essential to develop a methodology for the experimental validation of these solutions [19]. A particularly promising approach is the implementation of laser cutting systems that utilize industrial robots. These systems can be compared to flat CNC laser cutting machines, as they share many operational attributes, such as production flexibility, ease of digitization, offline working capabilities, and investment requirements. Laser cutting systems based on industrial robots are often more flexible and versatile in operation. They can be easily adapted to work with intelligent sensors and monitoring devices, and they are more conducive to modeling and simulation. This adaptability allows for laser cutting functionalities to be performed in offline mode, ultimately enhancing production efficiency and profitability [19].

The use of cutting various materials is known and used in industry. Several methods can be used, depending on the type of material and the use of energy, namely:

– Water jet cutting and abrasive water jet: The water is compressed to a very high level by a hydraulic pump and amplifier, and creates a vapour at very high pressure. In pure waterjet cutting, the supersonic jet destroys the material with its kinetic energy. But while the abrasive waterjet cutting, high-velocity abrasive particles are introduced into the chamber, and the water with the abrasive particles passes through a nozzle and strikes the surface of the cut and making the actual cut [14].

– Gas cutting (with oxygen or plasma): Gas cutting is achieved by a chemical/thermal reaction occurring with iron and iron alloys. Plasma arc cutting - electrically conductive materials are cut with the generated plasma [8].

– Cutting with a laser beam: While these cut the use of the intense energy laser beam, localized on a small spot on the surface of the material to be cut [2].

– Wire electrical discharge cutting: In this type, it is a thermo-electrical cut. The material is eroded by a series of sparks between the workpiece and the wire electrode [18].

In the developed article, laser cutting technology was used, which is mounted on a robot arm. This allowed the use of available infrastructure, but also increased the possibilities of cutting for customized products on individual orders. However, with the increase in production capabilities, several problems occurred during cutting. Due to the need to determine the causes of certain problems during laser cutting, it was decided that an analysis would be performed, for which the Ishikawa diagram method was used, in particular, since these are tasks carried out under specific conditions, for small-scale production and individual, specific products for special applications. In addition, the problem of cutting in the material, in this case tulle, also requires meeting specific customer requirements, who expect that the cut materials meet required quality standards and chemical purity levels.

## 2. MATERIALS AND METHODS

The cutting methods listed above are widely used in industry. They have their advantages and disadvantages. However, the article focuses on the laser light cutting method, but one of the innovative manufacturing methods was used, in which a laser is attached to a robot arm. The use of such a laser cutting solution on the robot arm allowed the use of the available infrastructure of the Department of Automation of Technological Processes and Integrated Manufacturing Systems, Silesian University of Technology, but also allowed the design in a 3D program and programming in the appropriate program of the cutting trajectory of the required shapes (Process Simulate), which accelerated the process of obtaining the specific shape of the material required by the client. Mounting the laser on the robot arm also allowed for obtaining a constant distance between the laser and the cut material and the speed of the arm with the laser. Programming the appropriate cutting trajectory also allows for repeated cutting of the indicated shapes, without the need for further programming of the robot. The repeatability of cutting is of great importance in this case, due to the specific use of the cut elements. In addition, the cut elements must meet the appropriate cutting standards, e.g., no melting, torn edges, and the so-called. chemical purity while maintaining the repeatability of the obtained shapes. This applies to the parameters for each cut material. In this case, the cutting process concerned a specific material, namely tulle. So, the combination of these solutions allowed for obtaining materials in which the surface of the material is important and should be as little damaged as possible. Because of using these materials in various processes, where mechanical or thermal resistance is important, such as in this situation in chemical processes. Importantly, also in [6], for the laser cutting process, it was determined that the following elements may affect the quality criterion: Cutting slot width; The slope of the inner surface of the crack; Perpendicularity of the cutting edge; The width of the heat-affected zone; Slag appearance, and Surface roughness.

To implement the laser cutting process, a station consisting of a Fanuc robot arm, was built Arc Mate 100iB robot, and a blue light-emitting laser (Department of Automation of Technological Processes and Integrated Manufacturing Systems, Silesian University of Technology, Figure 1).

It is a blue light laser with a power of 20 W. The wavelength of blue light is 450 nm. The focal length of this laser is 20 - 40 mm (it is a variable focal length laser). The thickness of the cut materials is, on average, (10 – 15)mm for plastics (depending on the hardness of the material). The cutting speed (laser head movement) was 5 mm/s.

Taking into account the customer's requirements and the indicated material (tulle), the laser cutting process was carried out, mounted on the robot's arm. The operation was possible thanks to the appropriate programming of the robot's movement trajectory, as well as the laser setting. The result of the sample cutting (bold shape) is shown in Fig. 2. The material (tulle) was in the form of a rolled-up bale of material, 10 meters long and 2 meters width. From this rolled-up bale, in this individual order, in final form, cutting 20 pieces. From the rest of the material, in the future will be cut another pieces.

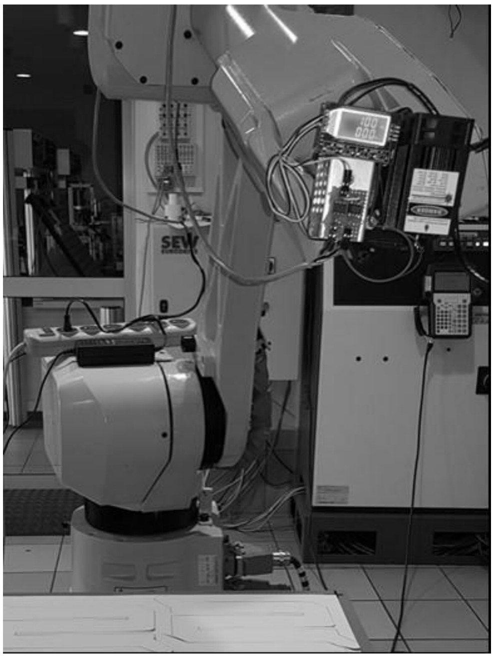

Fig. 1. Laser cutting equipment

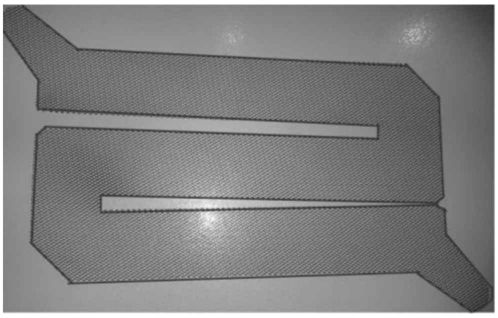

Fig. 2. Example of cut material

However, during the first attempts to cut the material, the assumed quality criterion was not met, which required an analysis of the entire cutting process. Therefore, it was decided to use the Ishikawa diagram to analyze the described material cutting problem. The obtained effects are described in the next chapter.

## 3. RESULTS AND DISCUSSIONS

Laser cutting offers many possibilities for producing materials, especially if other technologies are not working at the moment. The solution used in the article, which is an innovative combination because the laser is mounted on the robot arm, offers more possibilities for production. Laser cutting is precise, does not tear the edges of the material, and allows for cutting various precise shapes in the material. However, not all materials can be used due to the specific power of the laser. Mounting the laser on the robot arm allows for the use of the available infrastructure of small and medium-sized enterprises. Additionally, the written shape cutting program can be used many times, on different materials, which also increases the competitiveness of the company. However, the implementation of the laser cutting process requires a lot of analysis and testing, because initially, during the tests, not every element was cut and cut properly, in this case, the material used for cutting was tulle. In addition, the set of parameters in some cases resulted in overburning of the cut edges. Because the cut pieces are to be used under specific conditions in the chemical industry, a so-called purity of cut is required. The cutting tests carried out are designed to check whether a particular type of material is suitable for the laser cutting technique and to set the appropriate cutting parameters for specific materials without edge burning, which has been the biggest problem. For this purpose, as a first step, it was decided that an Ishikawa diagram would be used to analyse the causes that can cause edge overburning and a failure to cut through the material.

In connection with this, an analysis based on the Ishikawa diagram, in the form of a fishbone, was performed. In the literature, an analysis based on the so-called 5M+E combination is often described, in which the main causes are: material, man, method, machine, and management, and E – environment or 6M+E, where the 6M is measurement. But in the article, the 8M+E combination is used, where other elements like maintenance or money (financing) [5,9,15]. The use of a chart with a larger number of factors allows for a more in-depth analysis on the one hand. On the other hand, the risk of omitting important factors that affect the analyzed process is reduced. In addition, the use of a standard form of the chart guarantees comparability of the results of different analyses.

Taking into account the laser cutting process mounted on the robot arm and the tests performed, various effects were obtained, which did not always meet the requirements for the absence of burns and the general cleanliness of the material. Because the cut elements must meet certain quality parameters, the analysis performed allowed us to look at the entire cutting process. The analysis performed using the Ishikawa diagram is shown in Fig. 3. The analysis carried out showed that certain factors have a significant impact on obtaining the appropriate quality of cut elements. These elements must meet specific quality parameters. Due to the cutting of specific elements from a specific material for a specific application, they must be properly prepared. The problem that was noticed during cutting concerned burns on the edges and undercuts of the material. This is a significant problem, because the cut elements are to be parts of membranes for chemical processes, and the burn products can lead to contamination of chemical substrates.

The analysis performed allowed us to determine which sub-causes influenced this situation. The biggest influence was on: cutting speed, laser power, laser-material distance, perpendicularity of the cutting edge, the width of the heat-affected zone, and surface roughness. It also turned out to be important to control the oxygen supply to the laser cutting site. Finally, the analysis sped up the process of identifying problems during cutting and supported the implementation of the laser cutting process (in this case, the material being cut was tulle), and allowed the cut pieces to be achieved in the required shapes, without edge burning.

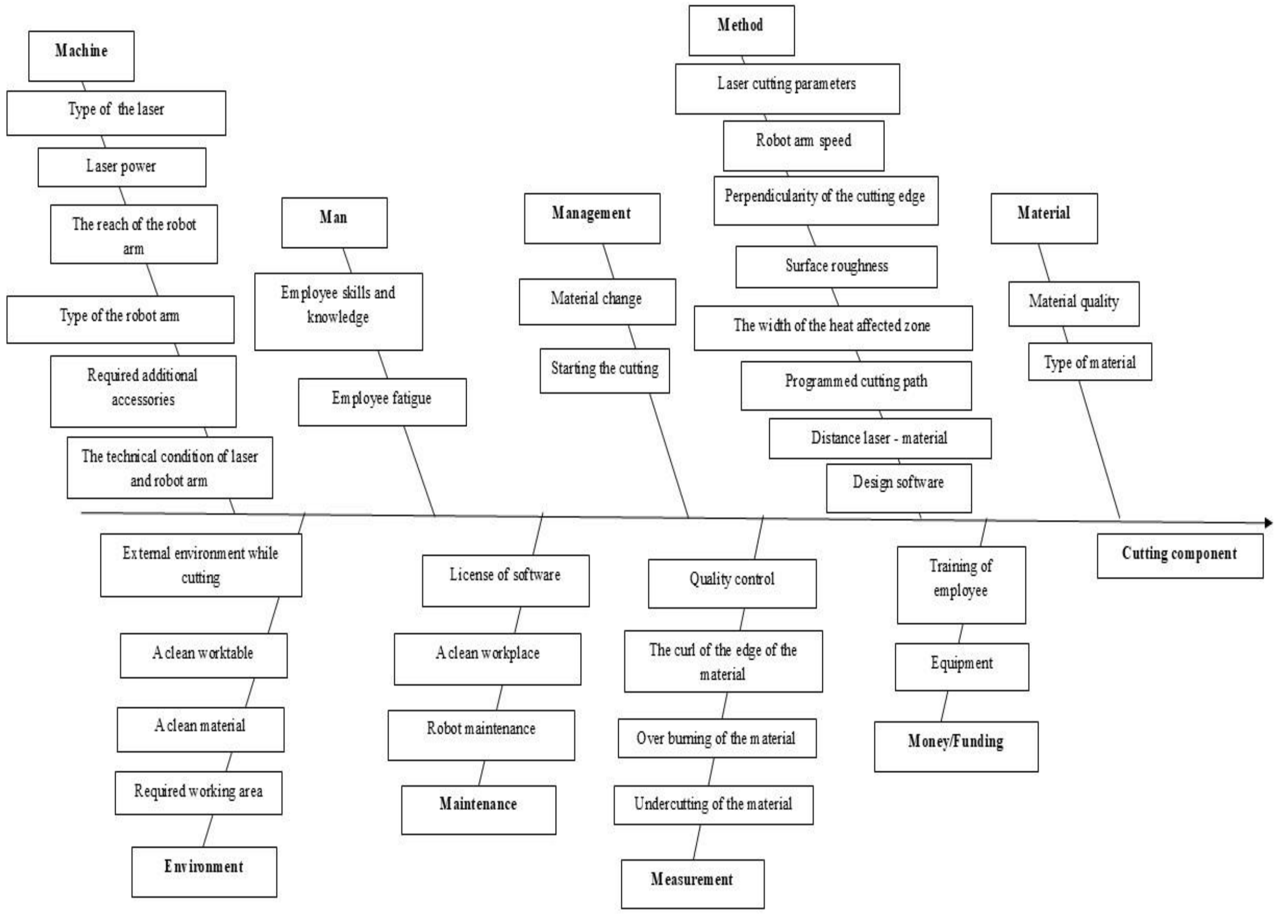


Fig. 3. Ishikawa diagram for the analyzed case

## 4. CONCLUSIONS

The use of laser cutting technology supports manufacturers in the production of specific products, while in the developed article, the laser is mounted on a robot arm, thanks to which the production possibilities are additionally increased. When carrying out the laser cutting process, a station consisting of a Fanuc Arc Mate 100iB robot arm and a blue light-emitting laser was built (equipped by the Department of Automation of Technological Processes and Integrated Manufacturing Systems, Silesian University of Technology).

In the article, in connection with the need to determine the causes of certain problems during laser cutting, it was decided that an analysis would be performed using the Ishikawa diagram method, in particular, since these are tasks carried out under specific conditions, for small-scale and individual, specific production, products for special applications. In addition, the problem of cutting in the material, in this case tulle, also requires meeting specific customer requirements, who expect that the cut materials meet required quality standards and chemical purity levels.

The example carried out showed that the presented solution effectively enables cutting of specific shapes in different materials (plastics). Before cutting, the desired shapes were carefully programmed and sent to the robot to ensure optimal efficiency and repeatability of the cutting process. This is the first advantage of the approach, i.e., expanding the possibilities of creating technology in the offline approach. During the tests, several challenges were identified, including determining the appropriate distance of the laser from the material surface, adjusting the cutting speed, managing the laser power, and establishing the robot coordinate system. In addition, thanks to the programmed movement of a robot, a cutting simulation was available in software (Process Simulate) that visualized the programmed robot movement trajectory. This simulation allowed faster analysis of the accuracy of the laser cutting path, which saved time during real tests on the robot. Ultimately, this efficiency translates into improved operational efficiency of companies, resulting in significant savings in both time and costs.

The problem that was noticed during cutting was related to edge burns and material undercutting. The analysis performed allowed for determining which sub-causes influenced this situation. The biggest influence on this was: cutting speed, laser power, the distance between the laser head and the cut material, perpendicularity of the cutting edge, the width of the heat-affected zone, as well as surface roughness. Therefore, in further research and work, changes concerning the above sub-causes will be investigated first, to obtain even better cutting effects. Research and analysis of cutting other materials will also be carried out, as well as the possibilities of further improvement of the constructed station.

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