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INVESTIGATIONS OF LASER CUTTING MODES ON THE QUALITY OF DIFFERENT CUT PARAMETERS

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Abstract

This paper is a review article that details the parameters of laser cutting on the quality of the cut, considered as a critical factor of performance, aesthetics and functionality. For certain gauge sizes, two main thicknesses of low carbon steel sheet are considered in more detail in terms of tolerance accuracy. The main conclusions relate to the quality of specified thicknesses at different, materials and capacities, for which manufacturing experience is also shared. From the study done, it can be determined that the laser cutting technology and its quality can be formalized by input-output, after specifying them, the quality can be identified. It is through this that the purpose of the study is realized.

Keywords: Laser cutting modes, Quality cut parameters, HAZ, Modeling, Multi-criteria optimization.

1. INTRODUCTION

The design mode of laser cutting technology is closely related to various parameters that ensure precision cuts. The key parameters include: Laser power (higher power can cut through thicker materials, but increases the heat affected zone (HAZ) and kerf width), scan speed (higher speeds can reduce HAZ, but can compromise cut quality), frequency (instrumentation affects cut smoothness and quality), pulse duration (shorter pulses can improve precision, but may require higher power) [1, 2].

When cutting low carbon steel with a laser, the tolerance range for dimensional accuracy according to literature data [3] can vary depending on the material thickness and cut dimensions. Typical accuracy tolerance ranges for low carbon steel are listed in Table 1. The tolerance values given in Tab. 1 are influenced by factors such as laser power, cutting speed and laser beam quality. The scientific literature supports these ranges. For example, research in the International Journal of Advanced Manufacturing Technology discusses how optimizing laser cutting parameters can achieve accurate tolerances

Table 1. Relationship between thickness, size and tolerance.

Size, mm	Thickness, mm	Tolerance, mm
Up to 50	3	±0,1
	8	±0,2
Up to 150	3	±0,15
	8	±0,3

Furthermore, guidelines from industry sources such as tolerance charts for CNC laser cutting provide similar tolerance ranges [4].

The ability to make the cut (Fig. 1) must be refined, for the individual representatives of the class in terms of the quality of the cut.

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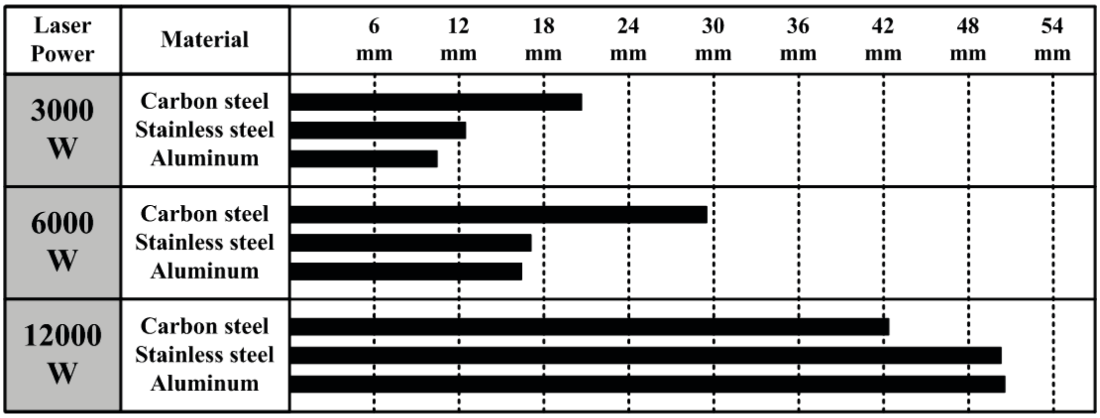

Fig.1. *Insight into the relationship between material and laser power, on the potential cutting thickness*

2. ACCURACY AND QUALITY OF CUT. FACTORS AND FEATURES AFFECTING QUALITY.

2.1. Accuracy features of CAD/CAM systems.

Accuracy refers to the conformance of the cutting dimensions to the intended design specifications. The laser technique provides the ability to make the process flexible by using the same equipment for different projects and reduces the need for additional tooling [5]. It has been shown that laser cutting is generally faster than mechanical cutting methods, while the material utilization ratio is greater. It is characterized by high precision due to its ability to focus a narrow beam of light on the material, resulting in minimal kerf width and heat affected zones (HAZ) [2].

This is what significantly reduces material waste. Integration with CAD software allows automation related to the accuracy of production processes. This integration allows directly to the construction of a common CAD/CAM information model related to productivity and product quality [6]. Furthermore, the integration of CAD with laser cutting systems facilitates real-time control and automation as described in a study of laser-assisted manufacturing processes [7, 8].

For several laser technological processes (cutting, welding, marking, hole punching, etc.) it is important to estimate the critical power density to reach the surface melting or vaporization temperature with an appropriate theoretical model is an important stage in the development of certain production technology. Using numerical experiments, these publications provide methods for preliminary investigation of the influence of wavelength, speed, and power density on laser technological processes [13, 14].

2.2. Generally accepted output quality metrics

The heat affected zone (HAZ) in laser cutting is significantly affected by the power density applied during the process. For 8 mm thick carbon steel, varying the laser cutting power density can cause noticeable changes in the HAZ. Increasing the laser power density typically increases the width of the HAZ. In [2, 9], it was found that increasing the laser power from 2 kW to 4 kW results in approximately 20-30% increase in HAZ width for carbon steel, but if optimization of mode parameters, such as decreasing the power density while increasing the cutting speed, can minimize the HAZ by up to 15-20%. Namely, these two facts show that selecting and optimizing laser cutting parameters control HAZ to achieve high quality cuts. Since quality is composed of several indicators, the concept of integral quality parameter (IQP) has been introduced in the literature as an overall quality assessment measure. The input parameters that directly contribute to the result are shaped into the following groups: process parameters (crucial for production); properties of the materials used in production (play an important role in quality and productivity); technological regime with the specific production techniques and technologies used.

The use of advanced technologies such as Artificial Intelligence (AI) in item manufacturing improves process quality by identifying critical quality approaches that traditional methods may miss [10]

The components defining the set of metrics related to the integral quality criterion relate to: surface roughness after cutting, defined as a measure of surface texture influencing the aesthetic and functional properties of the part; dimensional accuracy, reported as the degree to which the dimensions of the cut part conform to the specified CAD model; edge quality, accounting for the influence of product performance and safety; and heat affected zone (HAZ), as the area around the cut was defined, The integral criterion also considers the degree of defects, which is a characteristic of defects such as bumps, cracks or deformations. There is a drive for consistency, which is the ability to maintain uniform quality across multiple products or batches.

The application of the ability to analyse the individual criteria of an integral parameter is carried out by visual inspection, where obvious defects such as cracks, bumps and deformations are identified through the initial assessment. Surface roughness is determined by profilometers or laser scanners and the surface roughness parameters (Ra, Rz) are measured by these. Coordinate measuring machines and other precision measuring tools are used to check the dimensions of the cut parts against the specified values [11]. The microscopic examination and edge roughness measurements are used to assess the quality of the edges. Non-destructive inspection methods such as ultrasonic inspection, X-ray inspection and inspection by penetrators to detect internal and surface defects are also available, non-contact methods can also be used to measure and control the details after thermal cutting, such as the photogrammetric measurement method [12].

3. ANALYSIS OF RESULTS

The purpose of the research is to create an algorithm and regression model to optimize the deviation from the dimensions between the model and the cut contour by minimizing the error of this deviation. Based on the conducted experiment and the results of the research, a generalized methodology is created. Using the methodology, it is necessary to analyse the accuracy deviation depending on the parameters of the technological mode. The goal of the research is the most widely rolled steel C235. In The equipment we used is Fiber Laser Durma HD-F 4020/4KW, with general purpose for cutting sheet material with a thickness of sheet steel up to 20 mm, chrome-nickel steel up to 10 mm and rolled aluminum sheet up to 12 mm with sheet sizes up to 4064x2032. It is a dynamic laser machine characterized by intelligent cutting heads for its operations. These modes helped to plan the experiment with the modes shown in Table 3.

Table 2. Technological parameters for cutting black steel with a thickness of 3 mm

Type of mode	Speed, mm/min	Gas Pressure, Bar	Laser Power [W]
Fast	3000	0.5	2500
Mediu m	2400	0.4	2300
Small	2600	0.6	1700

After the cut contour with the corresponding mode, the difference between the set and received values can be determined. That can be done by measuring the actual diagonals after cutting for each process mode and on their basis determining the relative deviation from each diagonal.

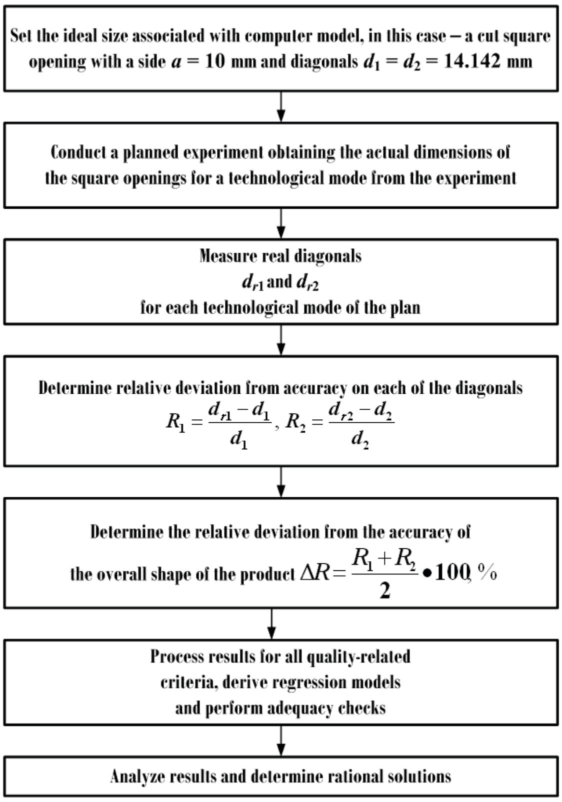

***Fig.2.** Methodology for determining the relative deviation from the shape of the dimensions during cutting*

Table 3. Planned experiment to derive a model for the model for the relative deviation from accuracy

№	V, mm/ Min	P, W	N, bar	Relative deviation, ΔR %
1	2400	1700	0,4	9.21
2	3000	1700	0,4	9.31
3	2400	2500	0,4	9.10
4	3000	2500	0,4	9.85
5	2400	1700	0,6	10.0
6	3000	1700	0,6	9.21
7	2400	2500	0,6	10.1
8	3000	2500	0,6	9.52
9	3000	2100	0,5	9.62
10	2400	2100	0,5	9.31
11	2700	2500	0,5	9.46
12	2700	1700	0,5	9.42
13	2700	2100	0,6	9.62
14	2700	2100	0,4	9.31

In Table 3, for each cut contour, a value for the relative deviation from the accuracy ΔR, % was obtained, for which a regression model was derived according to standard methodology [15].

After determining the relative deviation from accuracy for the two diagonals, the deviation from accuracy for the overall shape of the product can be determined.

Pre-cut experimental contours on the basisof which the plan of the experiment was formed

The model of relative deviation from accuracy ΔR, % in laser cutting has the form:

$\Delta R = 9.41593 - 0.023609\ X_1 + 0.107756\ X2 + 0.162448\ X_3 + 0.0719866\ X_{12} + 0.156836\ X_1X_2 - 0.337385\ X_1X_2 + 0.03429\ X_{22} + 0.0487461\ X_{32}$

An adequacy check was made for the model, the results of which are:

- Multiple regression coefficient R = 0.9517;
- Fisher test:

F calculated 6.0078 > F tabulated 4.8183 ($\alpha = 0.05, 8, 5$).

As a result of the verification, it can be determined that the model is adequate and can be used for prediction.

DEFMOT [16,17] identifies the goals of using experiments for the research indicator and specifies the practical considerations that drive the design. The conducted physical experiment helps to make decisions, to implement and discuss concepts that serve as a basis for all conclusions.

A common three-factor representation is shown in Fig.3. However, it violates the “local embedded in the global” principle, a principle adopted by our team in the analysis of multifactorial processes. The image in Fig.4 is a solution to the graphical representation used by DEFMOT. The advantage of implementing this principle is its essential importance in the development of the decision support system.

Fig.3 shows the organization of information when deciding with the DEFMOT system.

More useful for the decision-maker in the analysis of the corresponding response surface may be the image of a contour diagram with lines at a constant level, in which the value of the examined quantity is already set with a given color in a certain interval.

The regression model analysis with the DEFMOT system is shown in Fig. 4, where the response surface, the relative deviation from the accuracy ΔR, %, is depicted on the three-dimensional scale by projecting the corresponding color. The values in the interval [0 – 33.33 %] correspond to the technological modes associated with the smallest deviation from the desired dimensions.

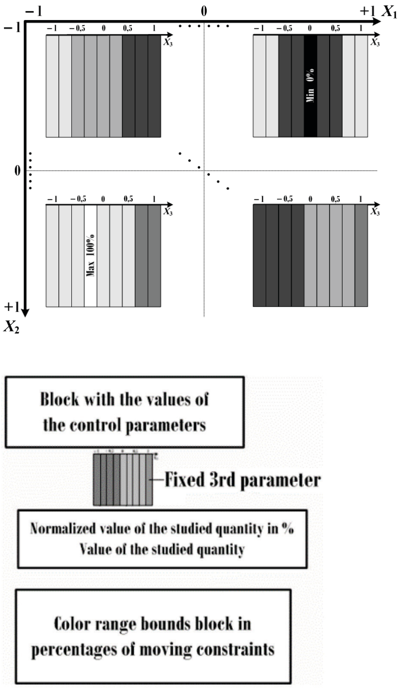

Fig.2. *The organization of information when deciding with the Defmot system.*

On Fig. 3 there is the complex influence of all three parameters. As proof of this, the following can be commented: the more accurate modes at the smallest pressure of the attesting gas at low speed – regardless of the power, and at the maximal gas pressures, the speed is maximal; the power changes from lowest to medium for the interval.

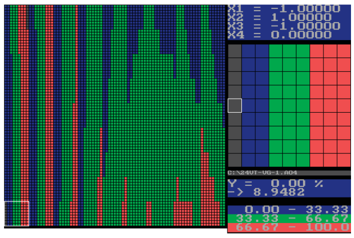

Fig.2. *Graphic interpretation of relative deviation from accuracy ΔR, %*

The conclusion made is fundamental to the interpretation of the regression model and it fully fulfills the set goal.

4. CONCLUSION

The review proved that the optimization of laser cutting parameters is well studied in the scientific literature. However, in this analysis, multi-criteria studies that formalize the set of quality indicators that identify, for a specific material, that performance regime that provides quality fitting to the specification requirements are absent. An example ToR analyses:

- Reviewing the laser cutting parameters, the cutting speed significantly affects the surface roughness, kerf width and heat affected zone (HAZ). This is what makes sense of the optimum cutting speed, ensuring low surface roughness and minimum kerf width are achieved, which are critical to maintaining uniform mechanical properties and minimizing defects.
- The balance between power and scan rate directly relates to the amount of energy input ensuring that the structural integrity of the material is maintained, preventing stress concentrations and potential mechanical damage.
- Research on optimizing laser cutting parameters using decision support systems has shown that the optimal cutting speed, and power are the most essential parameters related to achieving high cutting efficiency and quality. Such optimization minimizes defects and ensures consistent mechanical properties over the entire cut material.

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