Environment. Technology. Resources. Rezekne, Latvia
Proceedings of the 15th International Scientific and Practical Conference. Volume III, 445-448

Methodology and Model for the Study of Relative Accuracy Deviation in Laser Cutting of C 235 steel

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Abstract. **The paper presents an analysis using the design methodology based on the response of investigated quantities in the optimization of laser cutting parameters in terms of dimensional accuracy for C235 steel samples. The input factors, such as cutting speed, power, and carbon dioxide pressure, on the quality cut, expressed by the relative deviation from accuracy, are examined. The paper proposes an algorithm and a regression model to optimize the deviation from the dimensions between a model and a cut contour, by minimizing the error of this deviation. Based on the conducted experiment and research results, a generalized methodology was created. It can be used after a planned experiment to determine the accuracy of any contours of a test material of a specific thickness.**

Keywords: Laser cutting, laser cutting modes for C235 steel, modelling, multifactorial analysis.

I. INTRODUCTION

Laser beam machining (LBM) as an effective tool for material removal, is establishing laser treatment more and more as a technology in the industry. Precisely as an effective alternative to some conventional machining processes, LBM has attracted the attention of researchers to conduct extensive experimental and numerical research [1], [2]. Laser cutting is no exception in this direction, which is a non-contact, production-flexible and highly productive technique, allowing relatively accurate profiling of a wide range of sheet materials [3]. To obtain a high-quality result of laser cutting, an optimization process [4, 5, 6, 7] is usually started, which justifies the quality obtained and the costs incurred in terms of time and finances. Therefore, there is great motivation in modelling and optimizing this unconventional machining process. Modelling and optimization are performed based on related experiments. The experimental data formulate the relationship between the quality characteristic and the input parameters through the model and the response surface. The experiments were made using DOE (Design of Experiments) and the results were confirmed by analysis of variance.

In the references cited in this research, the DOE method such as the response surface method has been shown to be useful for deriving accurate mathematical models. Developing an accurate model between the input and output variables of the LBM process is difficult and complex due to the non-linear behaviour of the process under different conditions. There is no general formula or formulation in the general case. Each thickness or material, and laser equipment in the case of LBM, requires its own experiments. In them, the input variables are the system, material, and process parameters, and the output variables are the quality characteristics of the laser-processed part, including geometric characteristics, metallurgical characteristics, surface roughness, and material removal rate.

Algorithms for laser parameter optimization for laser cutting without irregularities are found in the references

Print ISSN 1691-5402
Online ISSN 2256-070X
https://doi.org/10.17770/etr2024vol3.8171

[8], which, however, are not related to the accuracy of the product between the set and the obtained contour. The cited algorithm involves designing experiments with only one factor at a time. The influence of more than one process parameter on the cut quality was discussed in [9], where the laser cut quality was analysed by notch geometry and surface roughness.

For the precise implementation of the technology, guaranteed accuracy is required. Unfortunately, the science team didn't find specific research in this regard. For this reason, it was necessary to apply the design methodology based on the response of the examined quantity when optimizing the parameters of laser cutting in terms of the accuracy of dimensions for C235 samples.

II. MATERIALS AND METHODS

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. It's chemical composition is show in Table 1.

TABLE 1. CHEMICAL COMPOSITION OF 235 STEEL

C	Si	Mn	Ni	S	P	Cr	N	Cu
≤0,22	≤0,05	≤0,60	≤0,30	≤0,040	≤0,040	≤0,30	≤0,012	≤0,30

TABLE 2. TECHNOLOGICAL PARAMETERS FOR CUTTING BLACK STEEL WITH A THICKNESS OF 3 MM

Type of mode	Speed, mm/min	Focus Off-set	Gas Pressure, Bar	Laser Power [W]	Frequency [kHz]
Fast	3000	3.7	0.5	2500	5
Medium	2400	3.7	0.4	2300	5
Small	2600	3.7	0.6	1700	5

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. The laser head has an integrated sensor system monitoring the cutting process and providing relevant information to the operator. In this way, it became possible to implement the technological modes provided for the implementation of the research goals. Each type of sheet metal contains three cutting technologies according to what contour is being cut. Fig. 1 shows the sample with pre-cut different contours for a 3 mm sheet of C 235 steel samples. The sheet steel cutting process takes place at a speed of 3000 mm/min in Fast mode (in which the outer contour of the square is cut, Fig. 1) and a beam power of 2500W. With techno medium mode, at a speed of 2400 mm/min, the inner four squares and the circle are cut at a power of 2300 W. With the techno small mode, at a speed of 2600 mm/min at a power of 1700 W, the four small circles are cut. Table 2 shows the cutting modes of the three contours. These modes helped to plan the experiment with the modes shown in Table 3.

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. 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. The formulas for these transformations are shown in the methodology algorithm, Fig. 2.

Fig. 1. Pre-cut experimental contours on the basis of which the plan of the experiment was formed

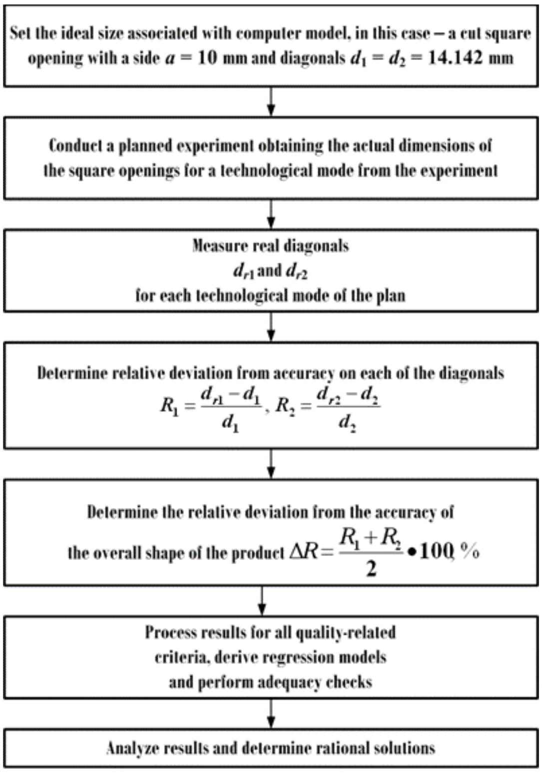

Fig. 2. Methodology for determining the relative deviation from the shape of the dimensions during cutting

The one described in Fig. 2 methodology can be successfully modified for 3D printing [10], where again there is a problem with a difference between set and received.

III. RESULTS AND DISCUSSION

Based on the preliminary experiments described in Table 1, an experiment is planned, which is as below:

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 from accuracy, 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 [11].

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

$$\Delta R = 9.41593 - 0.023609 \times X_1 + 0.107756 \times X_2 + 0.162448 \times X_3 + 0.0719866 \times X_1^2 + 0.156836 \times X_1 \times X_2 - 0.337385 \times X_1 \times X_2 + 0.03429 \times X_2^2 + 0.0487461 \times X_3^2$$

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 (α = 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 [12, 13] 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. [14] - [18]

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.

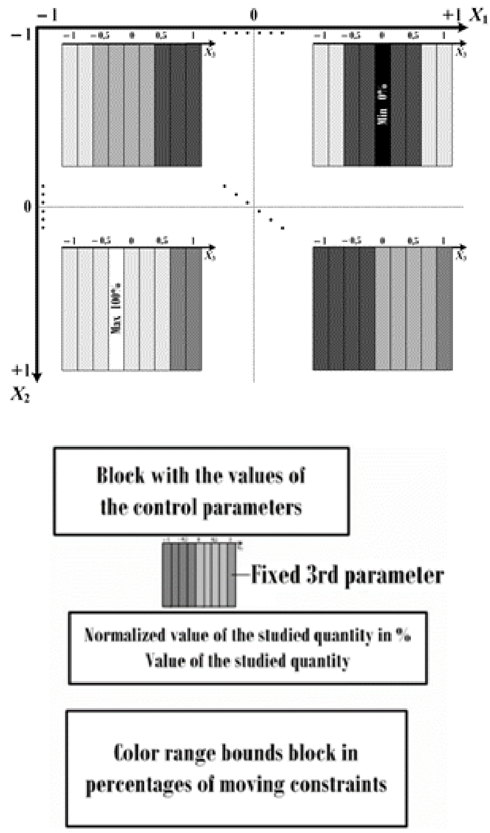

Fig. 3. The organization of information when deciding with the Defmot system.

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.

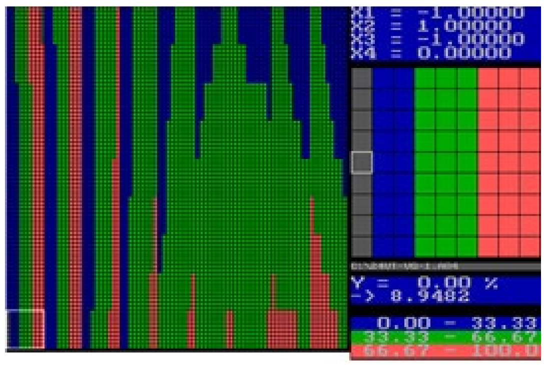

Fig. 4. Graphic interpretation of relative deviation from accuracy *ΔR*, %

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

IV. Conclusions

The research presents an analysis through the design methodology based on the response of the examined quantities when optimizing the laser cutting parameters in terms of dimensional accuracy for C-235 steel samples. Input factors such as cutting speed, power, and carbon dioxide pressure on cut quality, expressed as relative deviation from accuracy, were examined. It was found that the more accurate modes at the smallest test gas pressure required a small speed regardless of the power, and at the maximal gas pressures, they were associated with the maximal speed, and the power changed from the lowest to the average of the interval. To be able to draw this conclusion it was necessary to create an algorithm and a regression model to optimize the deviation from the dimensions between the model and the cut contour by minimizing the error of this deviation. For the implementation of the algorithm, it was necessary to conduct an experiment and to summarize the results of the research at the level of methodology. This methodology can be used after a planned experiment to determine the accuracy of any contours of a test material of a specific thickness.

V. Acknowledgments

This research was supported by project 2024 - FMME-01/link4077/, funded by the Research Fund of the University of Ruse.

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