JOURNAL OF ENGINEERING
annals OF
FACULTY OF ENGINEERING HUNEDOARA

MATHEMATICAL MODELLING AND SIMULATION OF THE EFFECT OF TECHNOLOGICAL PARAMETERS IN LBM STEEL CUTTING

Ivana HRABČÁKOVÁ

Technical University in Košice, SLOVAKIA

ABSTRACT:
The aim of the paper is to present mathematical model for simulation of the influence of technological parameters on quality parameters in laser cutting. The model was established on the basis of experimental measurements, and was verified on particular products. Presented model should serve as one of partial modules for assembling of complex control software assigned for technological parameters optimization in steel cutting with LBM (Laser Beam Machining) technology.
KEYWORDS:
mathematical model, optimization, simulation, technological parameters.

1. INTRODUCTION

Even though the hardware and software control of LBM technology has reached relatively high level, not all requirements on products quality are always taken into account [5]. Manufacturers of facilities focus on that part of software design which optimizes technological parameters in laser cutting, and thus the quality according customer's requirements is achieved. In present such programmes and sub-programmes exist, however quality requirements on optimal technological parameters adjustment are not always fulfilled. The parameters are consecutively adjusted -- on the basis of experience -- manually or are left on their tabular values. It must be noticed though, that tabular values of particular technological parameters are software-integrated and it is not possible to make their adjustments in program. Here is a gap that could be covered by the software established on the basis of mathematical models for particular technological parameters.

2. BASIC TECHNOLOGICAL PARAMETERS IN LBM PROCESS

To achieve required quality parameters of laser cutting process, optimal technological parameters values must be set up. Basic technological parameters have strong influence on surface roughness, as well as on micro-hardness modification of surface layers in cut area [7, 8]. Four groups of parameters are of special importance, these are shown in Table 1 [2].

Table 1. Basic technological parameters in LBM process

Laser parameters	Process parameters	Workpiece parameters	Machine parameters
- laser output - repeating pulse frequency - distribution of output density - output stability - beam diameter	- cutting speed - kind of gas - gas pressure - focus position	- material thickness - kind of material - surface quality - workpiece geometry	- laser unit output mirror - beam position - focusing lens - adjustment of laser beam - jet diameter

Laser output

Laser output must be adjusted to the type and thickness of workpiece. Following figure shows dependence of maximum material thickness on laser type [9].

Laser output can be adjusted in range from 1 to 100 %. Required high precision of complicated-geometry workpiece can be achieved by laser output reduction through the change of pulse operation length [8].

Beam diameter

Greater beam diameter ensures smaller focus diameter and thus also narrower cutting gap. Focus diameter depends on focusing length of applied converging lens. Focusing lenses of 2.5" focusing length provide focus diameter < 0.12 mm, lenses of focusing length 5" provide focus diameter < 0.2 mm.

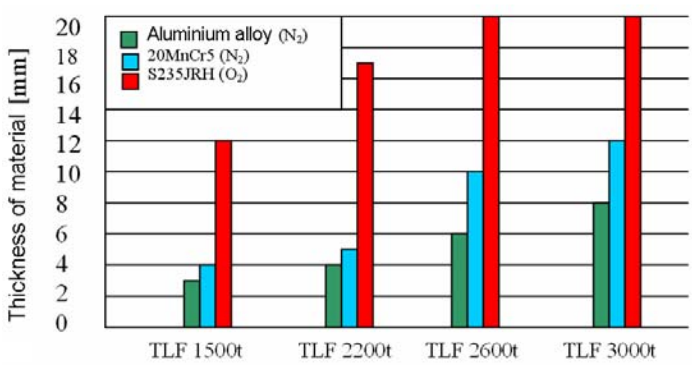

Figure 1. Dependence of maximum material thickness on laser type

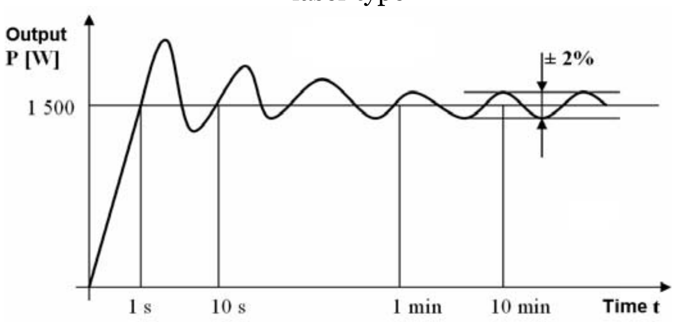

Figure 2. Momentary output at laser rise time

Cutting speed

Cutting speed has strong influence on depth and quality of the cut from the view point of roughness and micro-hardness [8]. With speed decrease, there is a significant growth of maximum cut depth, quality of cut surface grows too, because at lower speeds there is increase of energy needed for the destruction of material. Cutting speed depends essentially on the purity of applied cutting gases.

Gas pressure

Gas pressure markedly depends on material thickness of workpiece. In overfiring cutting, thin metal materials are cut at higher gas pressure than thicker workpieces, since higher cutting speed is applied. In high-pressure cutting, on the contrary, thicker workpieces are cut with higher gas pressure in order to expel dense meltings from the cutting gap. With growing thickness of metal materials there is an increase of cutting edge roughness and also higher laser output is needed for cutting.

3. EXPERIMENTAL EVALUATION OF SURFACE ROUGHNESS AFTER LBM CUTTING

Experimental samples were produced from steel EN ISO S235JRH (11 375).
Conditions applied at the experiment:

- machine: Trumatic L 3030
- laser type: Laser CO2
- samples material: EN ISO S235JRH (11 375)
- samples thickness: from 5 to 15 mm

Following table presents value ranges of technological parameters applied in experimental production of samples from EN ISO S235JRH (11 375) material.

Table 2. Value ranges of technological parameters applied in experiment

Material	Range of parameters			
	Laser output [kW]	Cutting speed [m.min^{-1}]	Gas pressure [MPa]	Jet diameter [mm]
EN ISO S235JRH	1 ÷ 3	1 ÷ 8.2	0.05 ÷ 0.45	0.7 ÷ 1.5

Roughness parameters Ra were measured on samples of thickness 5 to 15 mm in bottom, middle and upper contours of the cut.

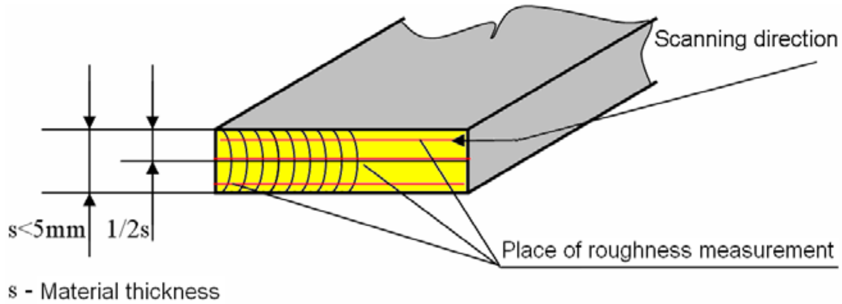

Figure 3. Experimental measurement of surface roughness ra on samples from steel EN ISO S235JRH

Following table presents measured values of surface roughness in dependence on thickness of experimental samples.

Table 3. Experimental values of cut surface roughness ra of en iso s235jrh steel samples

Sample thickness [mm]	Roughness of measured surface Ra [µm]										Mean value of surface roughness Ra [µm]
	Measurement number									Count of measure-ments	
	1	2	3	4	5	6	7	8	9		
5	3.14	5.20	3.86	3.41	1.35	1.56	3.58			7	3.157
6	3.11	3.93	3.45	6.11	5.69	4.54	8.61	9.155	8.865	9	5.94
8	14.07	9.97	11.78	12.2	13.5	10.12				6	11.94
10	15.95	11.77	9.36	12.32	13.68	9.04	14.4			7	12.36
12	15.26	14.32	11.54	12.63	13.66	15.8	12.36	12.67		8	13.53
15	12.71	7.76	18.96	17.25	17.55	21.26	21.42	7.35	19.20	9	15.94

4. MATHEMATICAL MODELLING AND SIMULATION OF TECHNOLOGICAL PARAMETERS IN LBM PROCESS

For quantification of various influences, it is useful to describe technological process by mathematical model. In cases when stable mathematical model – which structure would be compliant with technological process – can not be established due to influence of incidental parameters, it is necessary to apply simulation models [6]. Modelling and simulation of technological process allow for experiments apart from real object, without real intervention into operation, and gives an overall idea of the system state [1, 3]. On the basis of evaluation of mutual influence of technological parameters, the 3D graphical dependencies of technological parameters on material thickness and surface roughness value Ra were drawn.

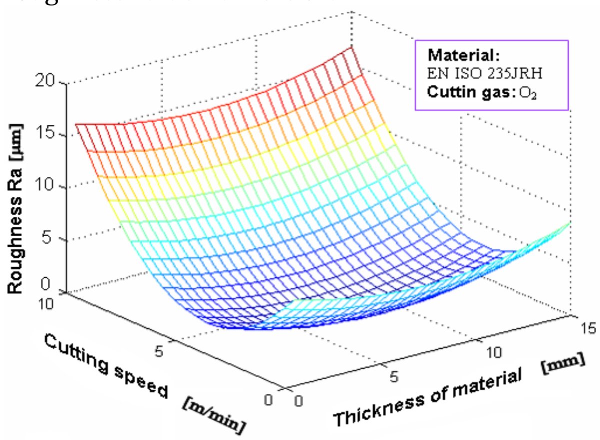

Figure 4. Dependence of cutting speed and material thickness on surface roughness value Ra

With growing material thickness lower cutting speed of laser beam is set up. 3D diagram (Fig. 4) shows, that surface roughness is suitable for midrange material thickness, i. e. up to 8 mm. Minimal surface roughness is achieved at 7 mm material thickness and cutting speed 5 m.min^{-1}. Optimal speed concerning influence on roughness is speed 8 m.min^{-1} at material thickness of 5 mm.

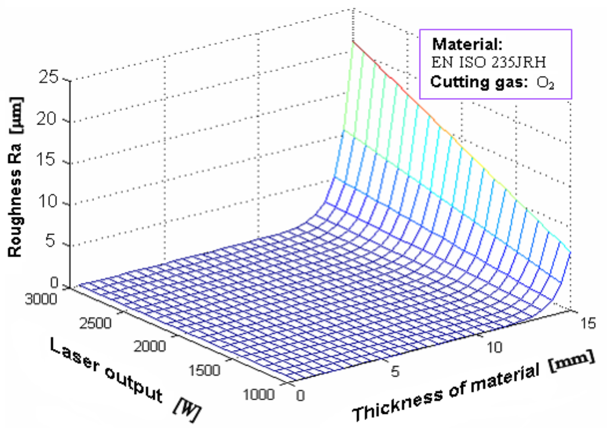

Figure 5. Influence of laser output and material thickness on surface roughness value Ra

From the 3D diagram (Fig. 5) it is clear, that growing laser output has not a significant effect on surface quality (roughness) up to 12 mm material thickness. For thickness exceeding 12 mm, roughness of the cut grows rapidly with laser output increase. Optimal setting appears to be 2.250 kW for laser output up to 12 mm material thickness.

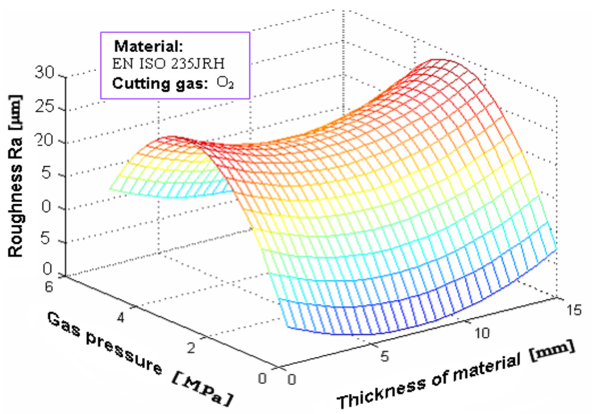

Figure 6. Dependence of surface roughness value Ra on gas pressure and material thickness

Gas pressure varies minimally in material thickness range from 5 to 15 mm. Surface roughness varies due to gas pressure change only marginally, and reaches its minimum values at pressure of 0.07 to 0.45 MPa. It was also found out that the roughness is minimal at material thickness from 5 to 6 mm, and optimum occurs at midrange thickness up to 8 mm and gas pressure from 0.4 to 0.45 MPa [3].

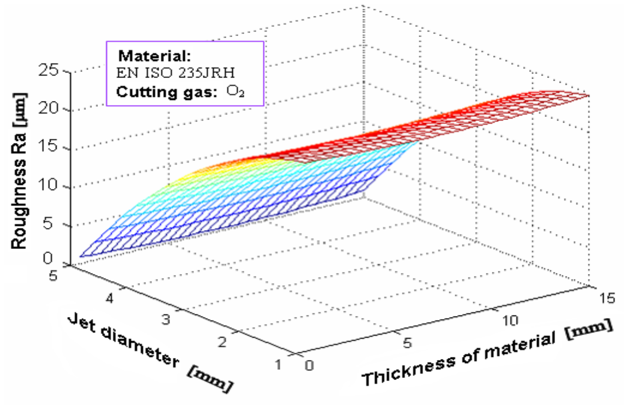

Figure 7. Dependence of surface roughness Ra on jet diameter and material thickness

3D diagram (Fig. 7) shows mutual relation of jet diameter, material thickness, and surface roughness value Ra. From the diagram it can be concluded that the change of the cutting head jet diameter with growing material thickness has significant influence on the variation of surface roughness value.

On the basis of the results of experimental measurements carried out on samples produced from steel EN ISO S235JRH, the mathematical functions of dependence were established for particular technological parameters. Then the mathematical model of the process was calculated by linear regression. The model is represented by function y_{Ra} [2],

$$Y_{Ra} = -0.61263\,x_1 + 0.04213\,x_1^2 - 0.00071x_2 + 2.5106\cdot 10^{-6}\,x_2^2 - 2.97978\,x_3 + 0.37544\,x_3^2 + 4.71338\,x_4 - 4.7452\,x_4^2 + 6.11118\,x_5 - 1.07245\,x_5^2 - 1.39781$$

- where particular variables x_1, x_2 to x_5 present values of forementioned technological parameters represented by diagrams.

5. THE CONCLUSIONS

The paper presents procedure for establishing of mathematical model for simulation of influence of basic technological parameters on surface roughness in LBM cutting. The aim was to elaborate foundation for proposal and realization of the software implementing established mathematical model. The purpose of the software is an effectiveness increase of the process of programming and setting up optimal technological parameters in LBM steel cutting technology.

REFERENCES

[1.] ČORNÝ, I., Matematický model tepelných parametrov, In: Operation and diagnostics of machines and production systems operational states: Scientific papers, Brno, Tribun EU, pp. 15-18, 2008.

[2.] FABIAN, S., HRABČÁKOVÁ, I., Kvantifikace vlivu technologických parametrů na parametry kvality při řezání laserem, Strojírenská Technologie, vol. XI, No. 2/2006, pp. 16 – 21., 2006.

[3.] FABIAN, S., STRAKA, Ľ., Prevádzka výrobných systémov, Edícia vedeckej a odbornej literatúry – FVT TU v Košiciach so sídlom v Prešove, Prešov, s. 252, 2008.

[4.] HRABČÁKOVÁ, I., Optimalizácia kvality a spoľahlivosť riadenia v aplikácii na rezanie laserom. PhD thesis, TU Košice, Prešov 2003.

[5.] MAŇKOVÁ, I., Progresívne technológie, Vienala, Košice, 2000.

[6.] MIHALČOVÁ, J., ČORNÝ, I., Metódy tribotechnickej diagnostiky na hodnotenie častíc vzniknutých opotrebovaním motorov, In: Operation and Diagnostics of Machines and Production Systems Operational States, Scientific Papers, Tribun EU, Brno, pp. 129-134, 2008.

[7.] STRAKA, Ľ., ČORNÝ, I., The influence of the technological parameters of the WEDM process on the surface roughness, In: CEEPUS, Modern Metrology in Quality Management Systems, Science Report, Project PL-0007, University of Technology, Kielce, pp. 257-265, 2006.

[8.] STRAKA, Ľ., Vplyv rezného prúdu a dĺžky trvania impulzu na zmenu mikrotvrdosti pri WEDM rezaní, In: Manufacturing Engineering, vol. 6, No. 4, pp. 23-25, 2007.

[9.] VASILKO, K., BOKUČAVA, G., Výrobné technológie, FVT TU Košice so sídlom v Prešove, 2001.

[10.] Company materials: Casspos a. s., Košice.