

Investigation of Cutting Width from Laser Power and Velocity

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Abstract: For production of lamellae for rotor and stator packages, as well as for transformers by means of laser cutting it is necessary to do preparatory experimental research in order to optimize the process. Investigations of the influence of the variation of laser power radiation and cutting velocity over the geometry of the cut are presented. Series of experiments were made with laser system TruLaser 1030 on samples of electrical steel (types M250-35A and M530-50A). An assessment of experimental results is made taking into account the cut quality requirements in accordance with the standard for cutting of thin materials.

Keywords: laser cutting optimization, laser power, cutting velocity, electrical steel

I. Introduction

Modern industrial production necessities of new electric motors and transformers in response to the requirements of energy efficiency are increasing nowadays, especially in view of the latest advances in automobiles and mechanical engineering automation development [2], [12], [14], [15].

This entails the search of a new technology for production of lamellae for rotor and stator packages as well as magnetic cores that can replace the old energy consuming and insufficiently flexible punching technology [9]. Such possibility is offered by the recent laser cutting technology which employs a new generation of hard body lasers (Fiber, Disk) that assure high accuracy and precision of treatment plus reliability and repetition of results [10], [16].

For implementation of laser cutting process through melting, which is most suitable for cutting of thin sheet material, a series of relevant factors has to be taken into consideration: laser source, physical parameters of material, and requirements of specific technology [4], [5], [6], [7], [8].

The following paper aims to make experimental researches for helping optimization on laser process through melting of electrical steel lamellae.

Investigations in the area of laser cutting technology present two basic technological parameters that are important for the process: power density of laser radiation q_s and time of impact [1], [3], [5], [8], [11]. These parameters are related through functional dependences with laser power radiation and velocity and present the main subject of investigation in the paper.

II. Presentation

Experimental investigations were made using industrial laser technology system TruLaser1030 [16]. The system has following basic modules: a laser source TruDisk 2001; an optical system for transport, direction and focusing of the laser beam; a power supply and control system; a work range with a possibility for movement of the laser beam along the axes x, y and z; a cooling system; a system providing auxiliary gas in the treatment area (fig.1).

Figure 1 laser technological system TruLaser 1030



Technological parameters of laser system are presented in table1.

Table 1 technological parameters of the system

TruLaser 1030	
working range	
➤ x axis, mm	3000
➤ y axis, mm	1500
➤ z axis, mm	75
max. speed v, m/min	60
accuracy of positioning, μm	25
power consumption, kW	8 - 35
laser stability at nominal power	$\pm 1\%$
focal length of the optical system, mm	200
diameter of laser light cable, μm	100
gas nozzle, mm	0,8 – 2,3
auxiliary gas	azot N_2
gas pressure, bar	4 - 20
laser source TruDisk 2001	
➤ frequency of following pulses, kHz	20
➤ wavelength λ , μm	1,03
➤ max. laser power P, kW	2
➤ min. diameter of working spot, μm	200
➤ beam quality BPP, mm.mrad	4

Metallographic method and microscope Neophot2 (magnification from 10 to 2000) are used for analysing geometry and quality of the cuts.

The experimental investigations are implemented on samples of electrical steel type M250-35A and M530-50A [13].

The studies are grouped in 7 series that include two basic tasks analysing the influence of:

- laser power radiation on the geometry of the cuts;
- cutting velocity on the geometry of the cuts, as well .

Experimental results

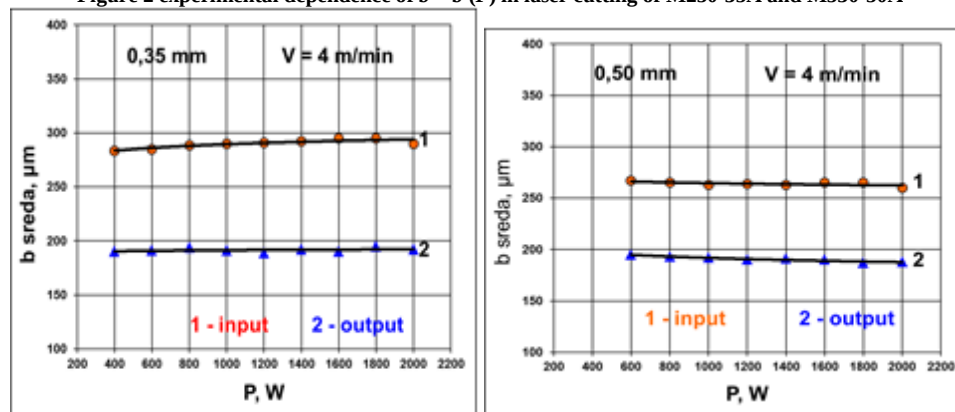
a). Studies of $b = b(P)$

In a series of four experimental groups the laser power varies in the interval of 400 W to 2 000W with step of 200 W while the cutting velocities of $v = (4, 8, 14, \text{ and } 20)$ m/min respectively are constants. During the experiments the following technological parameters are also constant – see table2.

Table 2 constant technological parameters during the experiments

TruLaser 1030	
nozzle diameter, mm	1,7
gas pressure, bar	14
focus position (M250-35A), mm	-1.85
focus position (M530-50A), mm	-2.00

Results of studies for both materials are given on fig.2.

Figure 2 experimental dependence of $b = b(P)$ in laser cutting of M250-35A and M530-50A

Similar graphical relationships are obtained with cutting velocities $v = (8, 14, 20)$ m/min.

Conclusions:

1. The variation of laser power P in the interval (400-2000) W with step 200W leads to no change of cut's width as well as on the surface on both entrance (input) and exit (output). Average values of width b in the studied range of power, are presented in table3. The maximum declination of $\pm 2,5 \mu\text{m}$ is in the range of the accuracy of measurement.

Table 3 average values of cutting width

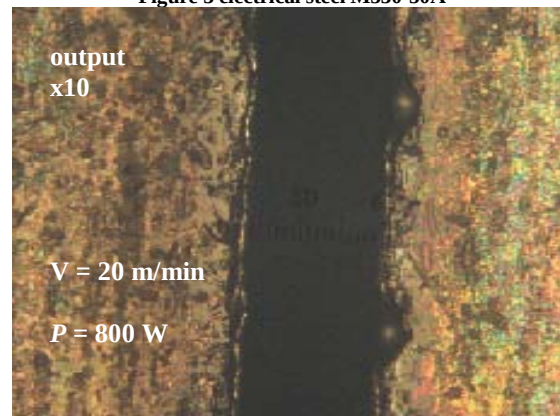
material	$b_{\text{input}}, \mu\text{m}$	$b_{\text{output}}, \mu\text{m}$
M250-35A	$290 \pm 2,5$	$190 \pm 2,5$
M530-50A	$264 \pm 1,5$	$191 \pm 2,0$

2. Throughout the entire range of investigation, cutting of the samples is observed, which can be explained as due to the high values of power density q_s ($9,64 \cdot 10^5 \text{ W/cm}^2 \div 4,82 \cdot 10^6 \text{ W/cm}^2$). With such values of power density in the treatment area temperature values larger than $T_m = 1880 \text{ K}$ (T_m melting temperature of the material) are reached, which is obligatory for carrying out laser cutting process by melting.
3. Investigations of the profile of the cut associated with perpendicular requirement (quality indicator according to standard DIN EN ISO 9013) show insignificant deviation in the studied range of power - see table 4. The explanation of this experimental result can be related with two factors: Gaussian distribution of radiation intensity and focus position.

Table 4 average values of deviation from the perpendicular of the cut

material	$\theta, ^\circ$ ($v = 4 \text{ m/min}$)	$\theta, ^\circ$ ($v = 8 \text{ m/min}$)	$\theta, ^\circ$ ($v = 14 \text{ m/min}$)	$\theta, ^\circ$ ($v = 20 \text{ m/min}$)
M250-35A	7.96 ± 0.24	9.37 ± 0.22	8.73 ± 0.82	8.68 ± 0.67
M530-50A	5.93 ± 0.67	6.57 ± 0.61	6.98 ± 0.20	6.48 ± 0.19

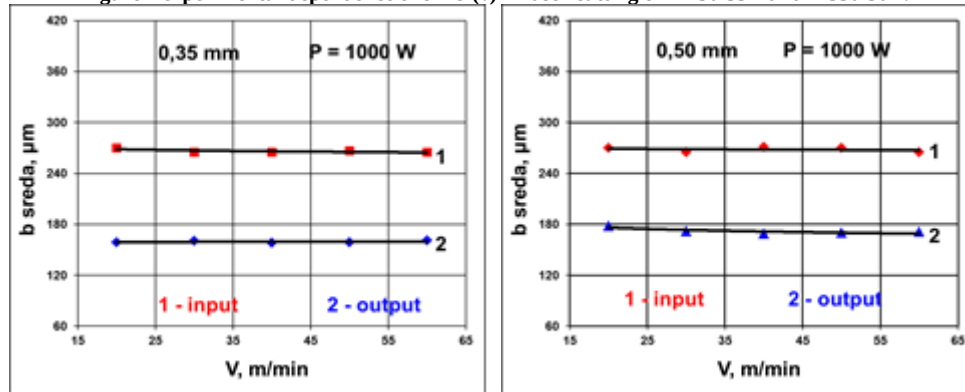
4. Observations and analysis of the cutting quality around the area of thermal impact indicate that at low power densities it deteriorates and at the output of the cut, droplets from the product appeared, discharged from the treatment zone see fig. 3. From laser powers $\geq 1000 \text{ W}$ to the end of the investigated range quality is significantly improved. The explanation is that in this power range power density increases and the materials are discharged in the form of vapour.
5. In terms of energy efficiency and quality requirements observations indicate that the optimum operation range is within (1000 -1400) W.

Figure 3 electrical steel M530-50A

b). Studies of $b = b(v)$

Three series of experiments have been conducted and cutting speed has been changed from 20 m/min to 60 m/min, with a step of 10 m/min in each of them at a constant laser beam power $P = (500, 1000, 2000) \text{ W}$. During the study the parameters that have already been given in table 2 remain constant. Graphical relationships of $b = b(v)$ for the two types of steel are shown in fig. 4.

Figure 4 experimental dependence of $b = b(v)$ in laser cutting of M250-35A and M530-50A.

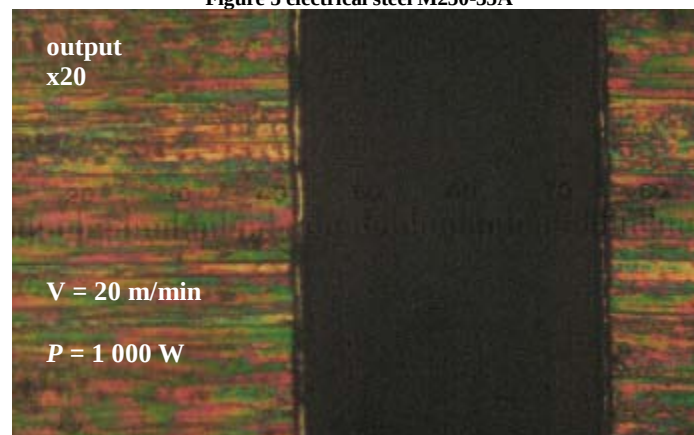


Similar dependences $b = b(v)$ of M250-35A, are obtained in the other two constant power sources of laser radiation.

Conclusions:

1. Changing of the cutting speed in the range of $(20 \div 60)$ m/min, with a step of 10 m/min does not affect the width of the cut at both entrance and exit. The average values of the cutting width b in the studied range speeds are as follows:
 - for M250-35A – $b_{\text{input}} = (255 \pm 2)\mu\text{m}$; $b_{\text{output}} = (144 \pm 2)\mu\text{m}$;
 - for M530-50A – $b_{\text{input}} = (272 \pm 8)\mu\text{m}$; $b_{\text{output}} = (185 \pm 10)\mu\text{m}$.
2. It was found that in this range both types of steel are cut but with laser beam power 1000 W and 2000 W. This is explained by the time of impact which while varying in the range of $690 \cdot 10^{-6}$ s to $230 \cdot 10^{-6}$ s is sufficient for obtaining a high-temperature T_m in cutting of electrical steel.
3. Metallographic observations on the heat affected zone show good cut quality at the moment of impact (the output lacks solidified material in the form of drops) - see fig. 5.
4. In terms of cut quality and correct operation of facility the optimum cutting mode for both types of steel is 20 m/min.

Figure 5 electrical steel M250-35A



III. Conclusion

The continuous demand of electrical machineries and equipment requires the development of new models with adequately improved manufacturing technology that meets modern energy efficiency standards. For decades punching technology was dominant in the manufacture of lamellae, however, recent years has seen its displacement by laser technology. It features exceptional flexibility, precise processing and high economic efficiency. Its main advantage is that it avoids expensive and time-consuming production of stamping tools (a punch and die set). The punching process is accompanied with plastic deformation of the material in the treatment zone when exercising pressure from the punch on the working surface. Through penetration in 5-8% from the thickness of a material, the stress in the area of the mechanical impact reaches a yield stress of the material. Increase of deformation leads to increased resistance and wear hardening appears. Laser technology overcomes these drawbacks. Experimental studies and analyses have confirmed the advantages of laser technology over punching. Additional studies planned to be carried out include a comparative analysis and evaluation of the size

and structural changes in areas of plastic deformation during punching and those deformations caused by the thermal effects in the laser method.

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