Influence of Defocus Position on Laser Cutting Process in Sheet Steel

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Abstract. Some researches about influence of defocus position to carry out laser cutting technological process through melting when producing lamellae for electric motors are presented here. Experimental series at defocus position Δf in the range – 3, 5 mm to + 3, 5 mm with two grade electrical steels M250-35A and M530-50A are described, too. The experiments are performed with a technological laser system TruLaser 1030. Functional dependencies of cutting width from defocus position b = b (Δf) have been shown. Theoretical relationships connected to the change of impact on a unit of area working spot over power density q_s of the laser radiation and interaction time t_{proz} (respectively cutting speed v), are examined too

Keywords: laser cutting, sheet steel, laser focusing.

I. INTRODUCTION

Production forecasts of electric vehicles show that over the next 10 – 15 years it will dominate over that of petrol and diesel cars [1]. Therefore for contemporary design new challenges are appeared to development and testing on new constructions of this type of cars. They impose demand for a new innovative technology when producing lamellae for stator and rotor packages of electric motors. Given the present punching technology for each new engine model it is necessary to make a special tool for production of new design lamella. This from technological and economic character is unprofitable. In general, the production of punching tool is connected with high costs and long time for its elaboration which are justified only in serial production. An innovative technological solution for cutting of lamellae by Si-sheet metal for the stator and rotor packages provides the laser technology for contour cutting.

For adopting of specific laser technology with given technological system for cutting of lamellae to production electric motors it is necessary to make thorough particular pilot studies. To achieve the desired quality during technological process it is important to test a number of parameters (figure 1) that are directly related to technology of the laser cutting such as: cutting speed v; power density q_s of laser radiation in the treatment area; repetition rate v; pulse width τ; defocus position Δf, etc.

In this paper the influence of defocus position as factor that is very important in processing of large size (3 000 mm x 1 500 mm) steel sheets will be examined. When processing such areas it is crucial to keep the optimum operating mode throughout the treatment zone
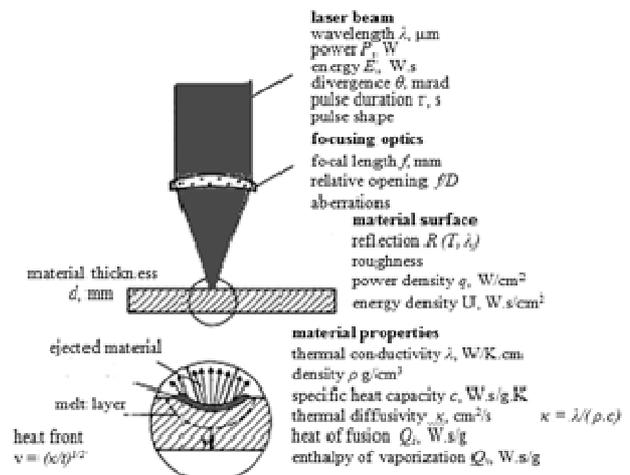

Fig. 1. Parameters which influence in the process of laser cutting [6]

The defocus position realized by the optical system provides the optimal diameter of spot d which in its turn is connected with two important technological parameters: power density q_s and impact time t_{proz}. [1,2,3,4,5].

II. THEORETICAL ASPECTS

In order to obtain a good quality in the process of laser cutting through melting, it is necessary the power density q_s of laser radiation and the interaction time t_{proz} to be at their optimum operating range providing the absorption of sufficiently energy with which could be melt material in the treatment zone

(fig. 2). Both technological parameters q_s and t_{proz} are connected with each other and with the diameter of the working spot d. Role of the working radius spot $r = d/2$ and its relationship with average power P and interaction time during the process are clearly seen from the dependence

$$t_{proz} = \frac{\pi^3 k^2 r^4 (T - T_0)^2}{4aA^2 P^2} \quad , \qquad (1)$$

where k –thermal conductivity;
P - average power;
A – absorption coefficient;
a – thermal diffusivity;
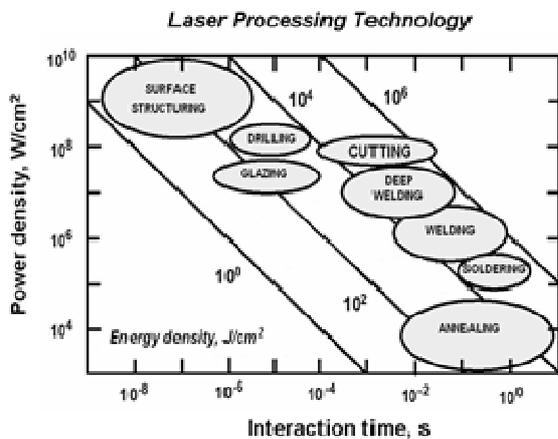T – process temperature;
T_0 – ambient temperature.

Fig. 2. Operational regimes for various processes of laser treatment

On the other hand power density in the area of working spot is given by

$$q_S = P / S, \qquad (2)$$

where S is a unit of area on the working spot,
P – power of the falling laser radiation on the surface.
Considering that

$$S = \pi d^2/4$$

where d is the diameter of working spot and substituting in (2) is obtained

$$q_S = 4P / \pi d^2. \qquad (3)$$

Diameter of the working spot d is a complex magnitude and it is connected with parameters for quality of the laser radiation (figure 3) and with these of the optical system as you can be seen from the following dependence

$$d = 2r = \text{M}^2 , \qquad (4)$$

where f is a focal distance,

D - beam diameter,
λ – wavelength of laser radiation,
M^2 – a parameter (a number to the diffraction – it describes an approximation of the actual laser beam with the Gaussian beam).

In the scientific literature M^2 is also described as K-factor – another measure of quality. It various between $0 < K < 1$. In the basic Gaussian mode TEM_{00} it is equal on 1. K – factor is related with wavelength λ, beam divergence θ and Gaussian beam waist r_0 as you can be see from the dependence

$$K = \frac{\lambda}{\pi . r_0 \theta}, \qquad (5)$$

where the divergence θ is defined with a limit of the relationship (fig. 4):

$$\theta = \lim \frac{r(z)}{z} = \frac{\lambda}{\pi r_0} , \qquad (6)$$
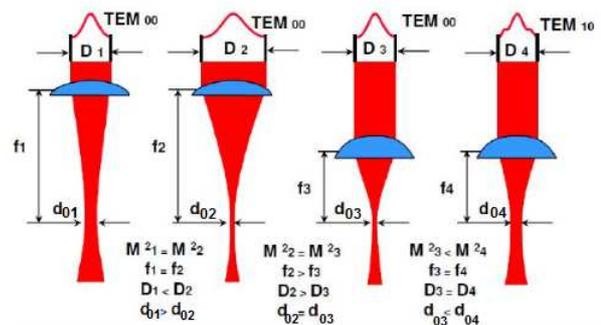

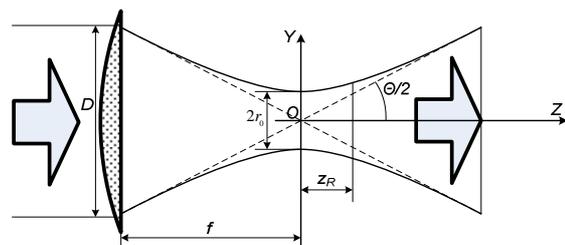Fig. 3. Role and meaning of M^2, D and f on the size of working spot d [7]

Fig. 4. A spatial distribution of the beam after its exit to the focusing system

A major parameter for the practice is the Rayleigh length z_R. It is defined as a distance from the beam waist (fig. 4) for which the cross sectional area of the laser beam is increased twice

$$z_R = \frac{\pi r_0^2}{\lambda} K = \frac{r_0}{\theta} \qquad (7)$$

To realize desired qualitative technological result unto laser cutting, diameter of the working spot or its position to the working surface often is required to

change by the optical system. Laser beam can be placed with three positions: inside the sample (fig. 5a), on the target surface (fig. 5b) and above the sample surface (fig. 5c). In cases (a) and (c) is operated at defocus position Δf. When the focus is above the sample surface, Δf has positive values, and when it is under the surface – negative values.

When defocus position Δf is above or under the surface, the power density q_s reduces very quickly in comparison the operating mode - $\Delta f = 0$. When Δf is larger than Rayleigh length (fig. 4), the diameter d of the working spot is given by equation

$$d = \frac{D(z' + \Delta f)}{f + z'} \,, \qquad (8)$$

where D is the diameter of laser beam that incident on the lens, f – focal distance of the lens, and the parameter z' is defined by expression

$$z' = \frac{d_f f}{D - d_f} \,, \qquad (9)$$

where df is diameter of working spot in focus.

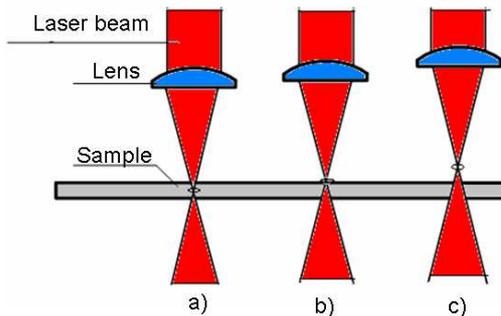Fig. 5. Location of the working spot to the sample surface: a). inside the sample ($\Delta f < 0$); b). on the surface ($\Delta f = 0$); c). above the surface ($\Delta f > 0$)

When condition $\Delta f < z_R$ is satisfied, the diameter of working spot almost does not change and therefore the power density of laser radiation reduces very small at compared to that in $\Delta f = 0$.

By the equation (8) we can see that if $\Delta f > z_R$ the increasing of defocus position Δf the diameter d of working spot is increased too, as the dependence is linear. The power density q_s is inversely proportional to the second degree of diameter d (3). It follows that the power density decreases very quickly with increasing of defocus position Δf, as well as optimal technological cutting regime is interrupted and required quality of cut is impossible to obtain.

III. RESULTS

To study the influence of defocus position Δf on kerf width b and quality, some experiments were carried out in conditions close to industrial system TruLaser 1030 [8]. Samples of electrical steel M250-35A and M530-50A suitable for lamellae of rotor and stator packages with thickness respectively 0,35 mm and 0,50 mm, are used. As a laser source in the system is Disk Yb:YAG laser emitting a radiation with wavelength $\lambda = 1,03$ μm.

On based our studies and methodic published in previous papers [9, 10, 11], to current report, the parameters systemized in table 1 are selected as constants. The study influence of defocus position Δf is realized in the range from –3,5 mm to +3,5 mm i.e. as well as with immersed focus and with taking out above the surface (see fig. 5).

There are studies on the effect of defocus position to the width input and output of the cut i.e. dependencies $b_{in} = b_{in}(\Delta f)$ and $b_{out} = b_{out}(\Delta f)$, are studied too. Concerning the quality of treatment zones and areas around them were carried out optical observations with microscope Neophot2 CARLZEISS JENA [12] at a magnification of 10 to 2 000 times.

Table 1
Technological input parameters for laser system trulaser 1030

Parameter	Value
power P , W	2 000
cutting speed v, m/min	50
repetition rate v , Hz	20 000
nozzle diameter ø, mm	1,7
pressure of N$_2$ p, bar	14
focus distance f, mm	200

Obtained results for functional dependencies of input width bin and output width bout to the defocus position Δf for both grade steels are given respectively in fig. 6 and fig. 7.
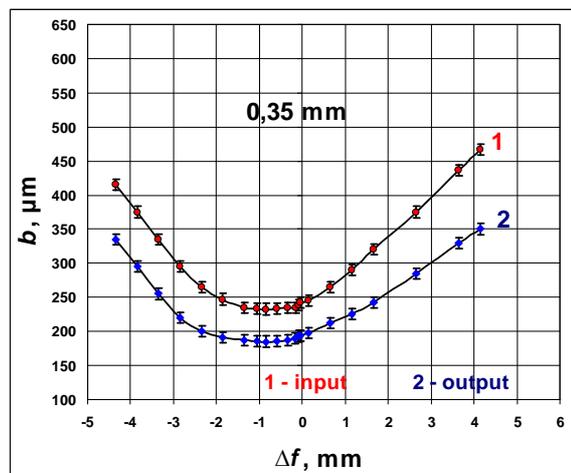

Fig. 6. Graphics of experimental dependencies $b_{in} = b_{in}(\Delta f)$ and $b_{out} = b_{out}(\Delta f)$ for samples M25-35A
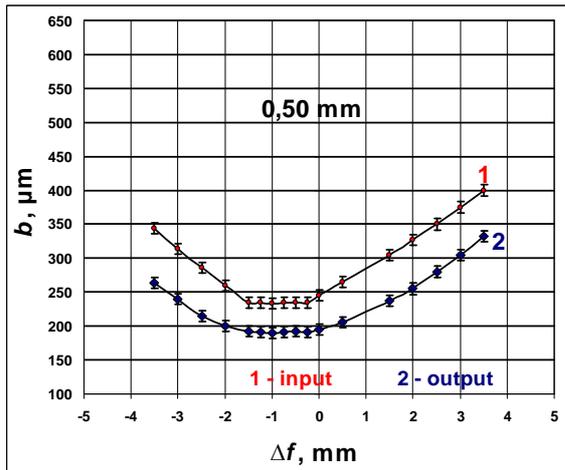
Fig. 7. Graphics of experimental dependencies $b_{in} = b_{in}$ (Δf) and $b_{out} = b_{out}$ (Δf) for samples M530-50A

Accumulated molten drops on the cutting edge are noted too on the samples with thickness 0, 35 mm when defocus position is $\Delta f > +2,65$ mm (fig. 8a) and $\Delta f > -3,5$ mm (fig. 8b).
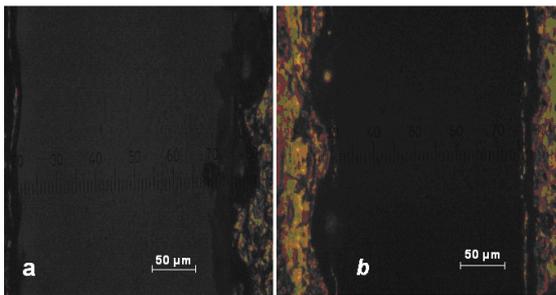

Fig. 8. Photographs of samples with tickness 0,50 mm and 0,35 mm at defocus margin Δf greater than +2,5 mm and –3,5 mm
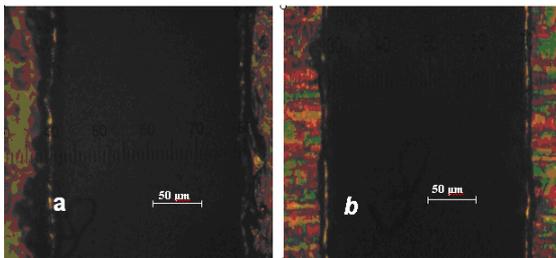

Fig. 9. Photographs of samples M250-35A at defocus position $\Delta f = -0,85$ mm and $\Delta f = -1,0$ mm for samples of M530-50A

Optical observations of cutting zone shown some good quality results at values of $\Delta f = -0,85$ mm (fig. 9) и $\Delta f = +0,65$ mm.

IV. DISCUSSIONS

From the analysis of experimental results it can be made following conclusions:

- With increasing of defocus position Δf in a plus direction up to $+3,5$ mm input cutting width b_{in} is increased nearly linear $\Delta b \sim 170$ μm. But in minus direction - $\Delta b \sim 110$ μm, i.e. there is a slight change of cutting width b at immersed focus in the material.

Such trend is observed and for the output cutting width bout.

- Left parts of graphics are little steep i.e. cutting width is changed faster in minus direction. This dependence is more strongly expressed for samples with less thickness: 0, 35 mm. The rate at which input cutting width increases in the interval to variation of defocus position $\Delta f = (0,65 \div 4,15)$ mm for M250-35A, was $\Delta b_{in} / \Delta f = 48,55$ μm / mm; and $\Delta b_{in}/\Delta f = 62,5$ μm/mm in the range $\Delta f = (-4,35 \div -1,85)$ mm.

- Significant change of the cutting width Δb in the range of defocus position $\Delta f = (-0,15 \div -1,35)$ mm for the samples of steel M250-35A and $\Delta f = (-0,25 \div -1,5)$mm - at samples of M530-50A, is not observed. This is explained by the fact that in the indicated interval are and the values of beam waist (Rayleigh length z_R). Cutting width is changed by $\Delta b = \pm 5$ μm in the above ranges of defocus position Δf.

- Microscopic observations and analyzes are shown a good cutting quality on the input as well as on the output when defocus position were in the range $\Delta f >+1,0$ mm and $\Delta f > 2,0$ mm for both samples. This is due to the fact that at these technological regimes obtained melt was removed well from the N_2 gas supplied in the treatment zone with pressure of 14 bar.

- Minimum input cutting width $b_{in} = 230$ μm was observed at $\Delta f = -0,15$ mm for samples of steel M250-35A, and $\Delta f = -0,25$ mm – for samples of M530-50A.

V. CONCLUSION

Studies have shown that the magnitudes q_s and t_{proz} influencing on the laser cutting process through melting of sheet steel material for lamellae of electric motors, are in complex dependencies with the diameter of working spot d and conditions of focusing as well as with a number variables connected with the beam quality. Knowledge of the relationships between them helps to shortening the path for optimization of the technological process – it enables to evaluate the effect on each of these parameters over the studying process. Experimental and theoretical analyzes are shown that the defocus position Δf is an important factor having an significant influence on the technological mode and on the quality of the processing. If you must use mixed units, clearly state the units for each quantity that you use in an equation.

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