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Study of Auxiliary Gas Pressure on Laser Cutting Technology

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***Abstract.** Two types of electrical sheet steel M250-35A and M530-50A were used to cut by melting with a TruLaser 1030 technological system. It was observed that pressure of auxiliary gas had a major effect on kerf width b and cut angle deviation α. Nitrogen as an assisted gas has been taken. The basic parameters as laser power, cutting speed, focus position were constantly supported and the pressure was changed from 4 bar to 20 bar by step 2 bar. As well as the experimental results of gas pressure on entrance and exit kerf widths, have been analyzed and discussed in this study.*

***Keywords:** laser cutting by melting, electrical steel, auxiliary gas pressure, kerf width.*

I. INTRODUCTION

Automobile industry is constantly developing. The automotive market can be divided into two main parts, automobile manufacturers and the so-called independent segment, primarily charged with creating modules, replacement parts, and accessories intended both for installation in new vehicles and for aftermarket sales. As a result, the manufacturers of replacement parts and vehicles (occupying top positions in terms of total value of production, export volume, investments, and employment), look for new technology to made them rapidly, flexible, easily and with higher quality [1]. For example, American manufacturer of Tesla Motors reported that he has the best quarterly results in his history and in the first quarter of 2015, 10 030 cars have been made. Over the same quarter of the last year this represents an increase of 55 % [2]. Development of electrical vehicles production in this trend will increasingly strengthen. Basic module in this type car is an electric motor.

Over the past decade laser cutting has become into state-of-the-art automotive technology. As a new technology about rapidly designing, developing and testing of new constructions motors, is appeared laser technology. It offers a higher quality and flexibility when solving new constructive ideas. Laser cutting is an energetically and economically advantageous solution when cutting electrical steels for rotor and stator packages (figure 1) to electric cars.

In practice there are three methods of laser cutting: oxygen, through melting, sublimation (figure 2). They are happening at different temperatures, as well as they differed with their technological parameters and characteristics (figure 3).

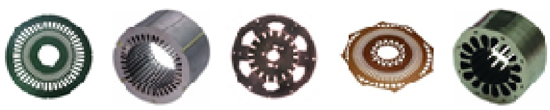

Fig. 1. Rotor and stator lamellae and packages [3]

Criteria defined quality of the process are [4]:

- deviation from the required profile and dimensional tolerances;
- perpendicularity and angularity deviations of cuts (DIN EN ISO 9013:2003-7);
- widening of kerf;
- kerf roughness;
- lack of slag.

They are dependent on some factors. The main of them are: material properties; characteristics of a laser source; cutting speed; passing of an auxiliary gas, focus position, etc. (figure 3) [5, 6].

To realize a qualitative laser cutting technological process it has to choose a suitable laser source, as well as the auxiliary gas, gas nozzle and gas pressure [7].

For cutting of thin metal sheets in the industry have been mostly used disc Nd:YAG and Yb:YAG lasers, providing power densities from 10^7 W/cm^2 to 10^8 W/cm^2, sufficient to implement laser cutting process through melting.

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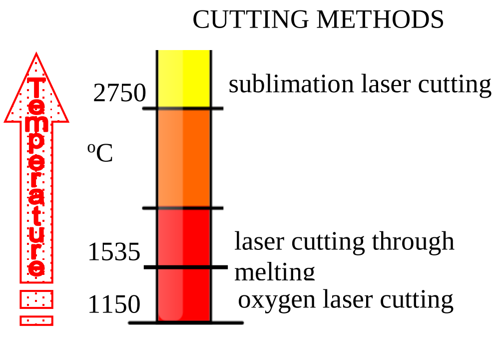

Fig. 2. Temperatures for electrical steel with which are realized the three methods of laser cutting

An almost parallel laser beam, which is usually invisible, is generated in the laser source and directed to the cutting head by mirrors, where it is focused by a lens on a small spot. In a treatment zone material is melted and ejected under the influence of inert gas flow which is directed to cutting area (figure 4). Simultaneously the gas puts pressure onto melts as well as hinders oxidation process and cools the processing area as helping to avoid forming a large heat affected zone around cut edge.

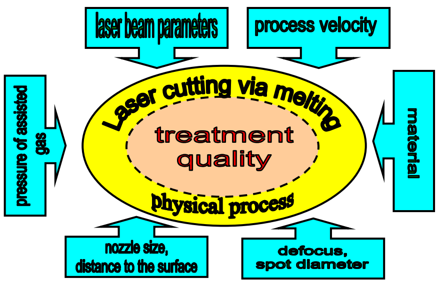

Fig. 3. Factors influencing on treatment quality of laser cutting process

The choice of optimum operating mode to submission of the auxiliary gas during the technological process is crucial for the quality in laser cutting process through melting. Two factors influence on forming of gas flow. From the one side are nozzle type and form, as the other one is distance between nozzle and working surface (figure 4). In modern technological system this distance is controlled by special sensor with aim to keep up optimum mode of treatment although possible defects on metal surface sheet.

Nozzle type for laser cutting through melting is different by these for technological operations as welding and hardening. In this kind of operation is important the nozzle diameter to be elected so that it is correspond with cutting width in the material. Only a certain portion of gas flow entering through nozzle is directed and came into the groove of cutting area. The distance from the nozzle end to the working surface is chosen depending on the design of the nozzle itself (its diameter). In the most general case it must be less than diameter of the nozzle itself, in order to avoid advent of turbulence and decreases of the pressure. For smaller distances itself slit is appeared as additional small nozzle, that has a favorable influence on the processing quality.

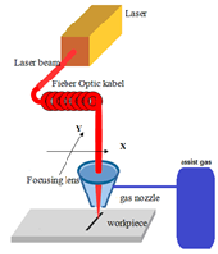

Fig. 4. Laser cutting by melting with assist gas

When cutting of thin sheet material having a thickness up to 1 mm with a good approximation, it may be considered that the parameters of gas stream are remained constant. In this case, a pressure gradient $\frac{\partial p}{\partial z}$ along the channel cut in realization of an isentropic process is given by the equation

$$\frac{\partial p}{\partial z} = \frac{p_{in} - p_a}{h} \quad (1)$$

where p_{in} is gas pressure on the enter,
p_a – atmospheric pressure,
h – thickness of the sheet.

When it comes to work with larger distance between the nozzle and working surface it is necessary the nozzle to be special designed for this purpose. Particularly this concern about the cases of gas pressures higher than 2 – 3 bar. Standard nozzles are with a diameter of 0,8 – 3,0 mm, as working distance is kept in the range of 0,5 – 1,5 mm.

II. EXPERIMENTS

Some series of experiments were done to investigate the influence of auxiliary gas pressure (nitrogen) on the geometry and cutting quality. The pressure was changed in the range from 4 bar to 20 bar by step 2 bar. Experiments were performed of prior prepared samples of electrical steel M250-35A and M530-50A. As a laser source was used TruDisk 2001. Technological parameters which in the course of studying remain constant are given in table 1.

Table 1
Technological parameters that were constant during experiments

Parameter	Value
Power of laser radiation *P*	2 000 W
Cutting speed *v*	50 m/min
Impulses frequency *ν*	20 000 Hz
Nozzle diameter	1,7 mm
Defocus position *Δf* (0,35 mm)	- 1,85 mm
Defocus position *Δf* (0,50 mm)	- 2,00 mm

The laser cut quality was monitored by measuring kerf width on the surface of electrical steel. The kerf width was measured with Neophot 2 CARLZEISS

JENA magnified 10 – 2 000 times. Both the entrance and exit surfaces kerf width (b_{entr}, b_{exit}) were measured.

When the cutting process by melting has been performed, in the processing area was observed a cut angle deviation (figure 5). To studied this effect we used a developed by us methodic based on Standards DIN EN ISO 9013:2003-7 and DIN EN ISO 12584 [8]. The deviation of perpendicularity is defined by line segment u = AB or with that of cut angle α ($tg\alpha$ = AB/BC),

where u = AB = (b_{entr} - b_{exit}) / 2,

BC = z – lamella thickness

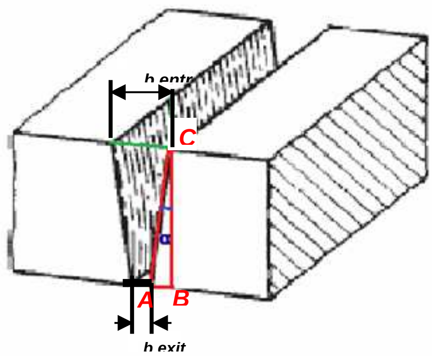

Fig. 5. Deviation from parallelism of the walls of cut

III. RESULTS OF STUDY

Dependence *b* = *b* (*p*)

Intervals of measured values cutting widths b_{entr} and b_{exit} in research range of gas pressure are shown in table 2.

Table 2
Alterations of kerf widths in studied pressure range

material thickness, mm	b_{entr}, µm	b_{exit}, µm
0,35	273÷283	182÷192
0,50	278÷288	180÷190

The results obtained for functional dependences of entrance width b_{entr} and exit width b_{exit} by pressure of inert gas p about samples of two blade steels (with thickness 0,35 mm and 0,50 mm), are shown respectively in figure 6 (a) and figure 6 (b).

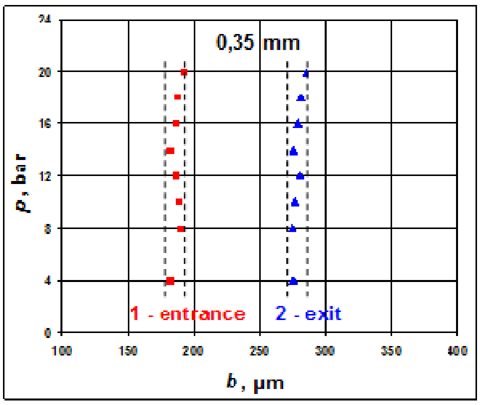

Fig. 6 (a)

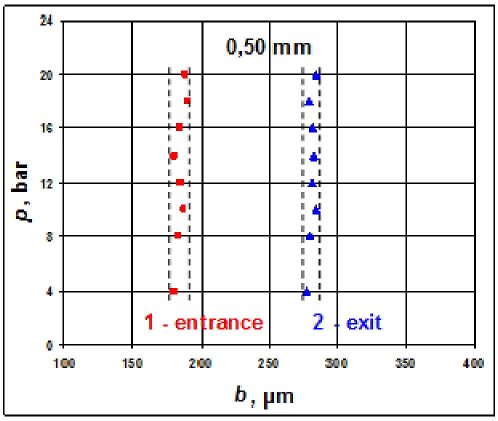

Fig. 6 (b)

Fig. 6. (a), (b) Experimental dependences of $b_{entrance}$ and b_{exit} as a function to technological gas

Dependence *α* = *α* (*p*)

When is carried out the experimental series (auxiliary gas pressure p - angle of inclination α) the pressure is increased in specified above interval, as the values given in table 1 were kept constant, too.

The results obtained for functional dependences $\alpha = \alpha$ (p) for two type sheet materials, are shown in figure 7.

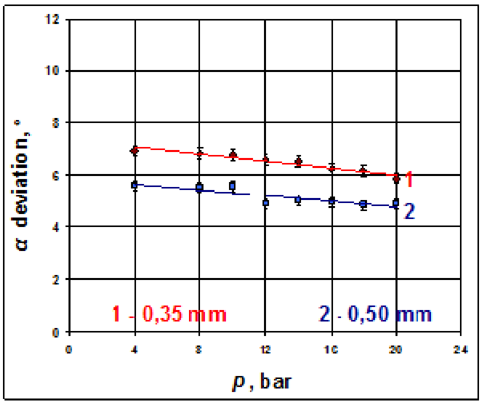

Fig. 7. Influence of pressure p of the auxiliary gas nitrogen on the angle of deviation from parallelism of the walls of cut $\alpha = \alpha$ (p)

IV. DISCUSSION

Experiments that were conducted in studied ranges allow doing the following conclusions:

- ✓ Cutting widths b was kept constant during the studied interval of pressure p of the auxiliary gas. The alteration of the pressure in the interval 4 ÷ 20 bar is connected only with changes in cutting widths $\Delta b_{entr} = \Delta b_{exit} \approx \pm 5$ µm about the samples of two steel grades. Maximum deviation of Δb is on the order of accuracy measurement.
- ✓ About both samples of plates with thicknesses respectively 0,35 mm and 0,50 mm, rapidity with which varies the cutting width Δb by gas pressure p, has minimum values, as:
  - cutting width on the entrance

- $\frac{\Delta b_{entr}}{\Delta p} = 0{,}56\frac{\mu m}{bar}$ for samples with 0,35 mm;
- $\frac{\Delta b_{entr}}{\Delta p} = 0{,}50\frac{\mu m}{bar}$ for samples

  - cutting width on the exit
- $\frac{\Delta b_{exit}}{\Delta p} = 0{,}38\frac{\mu m}{bar}$ for samples with 0,35 mm;,
- $\frac{\Delta b_{exit}}{\Delta p} = 0{,}31\frac{\mu m}{bar}$ for samples with 0,50 mm.

Larger values of the ratio $\frac{\Delta b_{entr}}{\Delta p}$, than those of $\frac{\Delta b_{exit}}{\Delta p}$ are due to the fact that the processing were realized from surface heat source and absorbed laser radiation has a Gaussian intensity distribution.

- ✓ The angle α decreases with increasing pressure p of the auxiliary gas nitrogen. Changing the pressure from 4 bar to 20 bar generated minimal changes in the angle $\Delta\alpha \approx 10$.
- ✓ Optical analyses of the processing area showed that at values of the pressure p less than 8 bar cutting quality are getting worse. Below this gas pressure at the set out experimental technological parameters it is impossible to be disposed entirely and molten material from the processing area. The molten material is postponed on the output kerf as thus forming drops and other imperfections (figure 8).

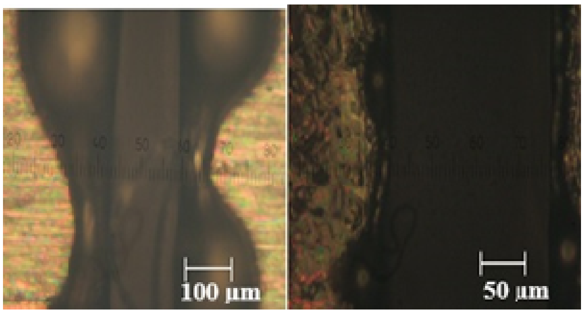

Fig. 8. Sections on cutting parts of samples with 0,35 mm (left photo) and 0,50 mm (right photo)

- ✓ The indicated interval $p = (10 \div 14)$ bar during laser cutting by melting with technological system TruLaser 1030 for samples with thickness 0,35 mm and 0,50 mm is proved optimal for achieving qualitative indicators about cut.

V. CONCLUSION

Actually, in the scientific literature there are a limited number of studies and analyzes for the processes as well as the efficiency to removing of melt from channel zone and formation of slag.

The complexity of the physical picture and also the practical needs required to maintain a high activity of research in the field of study of parameters related to gas supply.

It is interesting to investigate in addition to the role of the pressure of the auxiliary gas and that the distance from the edge of the nozzle to the work surface, and the change in diameter of the nozzle. This is planned in a future series of experiments. Such research will complement and enrich the picture of the interaction of laser radiation with matter and will eventually optimize the entire process more widely.

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