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Investigation on the influence of the process parameters power and velocity to laser cutting of lamellae

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The continuous development of mechanical engineering, automotive, electronics, etc. entail to the need for developing of new systems to electrical drives and mostly of the base module electromotor in them. Simultaneously with the design of the new drawing it is necessary in short terms to produce a test series for a rapid trial-run. These requirements give rise and the need of searching on a new technology in the production of lamellae for stator and rotor packages of the electric motors.

The paper examines the investigations related with the new laser technology for cutting through melting with disk laser TruDisk2001 of sheet material by electrical steel. The influence of laser power and cutting velocity are discussed to obtaining qualitative cuts. On the basic of a number of experimental studies are defined and taken out recommended working intervals for cutting of sheet material with 0.35 mm and 0.50 mm thickness.

Key words: laser cutting, disk laser, lamellae for rotor and stator packages

INTRODUCTION

Forecasts for the electric cars production shown that over the next 10 to 15 years it will dominate over that of diesel and petrol driven cars [1]. Therefore toward the modern design, development and testing of new mechanism for these types of electric cars appear new challenges. These entail and the demand for new production technology of lamellae for stator and rotor packages of the electric motors. In the existing until now punching technology for each new model motor it is necessary to make a special tool for production of a new design lamella. In principle, the production of the punching tool will entail great expense and long time for its elaboration which are justified only in large-batches production [2]. To small series and prototypes is necessary to search and develop a new technology for cutting. Such innovative technological solution for cutting of lamellae from Si-plate for the stator and rotor packages can be supplied by the laser technology on a contour cutting.

For the introducing of concrete technology for cutting of lamellae in production of motors is necessary to do some extensive specific studies [3, 4]. This is indispensable especially now after the appearance of a number of new, highly efficient lasers from a new generation - disk and fiber lasers [5, 6] providing high accuracy and production in the cutting process.

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PRESENTATION

In the recent years for the preparation of lamellae are mainly used multi-position punches, see Fig. 1. For example, presses with four- and six- position punch are used for asynchronous motors [7].

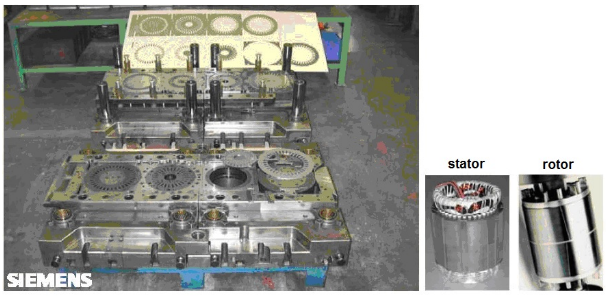

Fig. 1. A four-position punch for rotor and stator lamellae.

Despite its high performance the punching method has several disadvantages:

- ✓ A high cost of the punch (punches of solid metal-ceramic alloys are 2 to 3 times more expensive and with 2 times longer period of technological manufacture than those with high-alloy instrumental steels;
- ✓ A passage through several subsequent positions to give the final product (the lamella);
- ✓ Receiving defects: a strong distortion of a cutting detail, rounding of the cutting edges, breaking the edge of the cuts and burrs (especially large when the punch is wearied – see Fig. 2);

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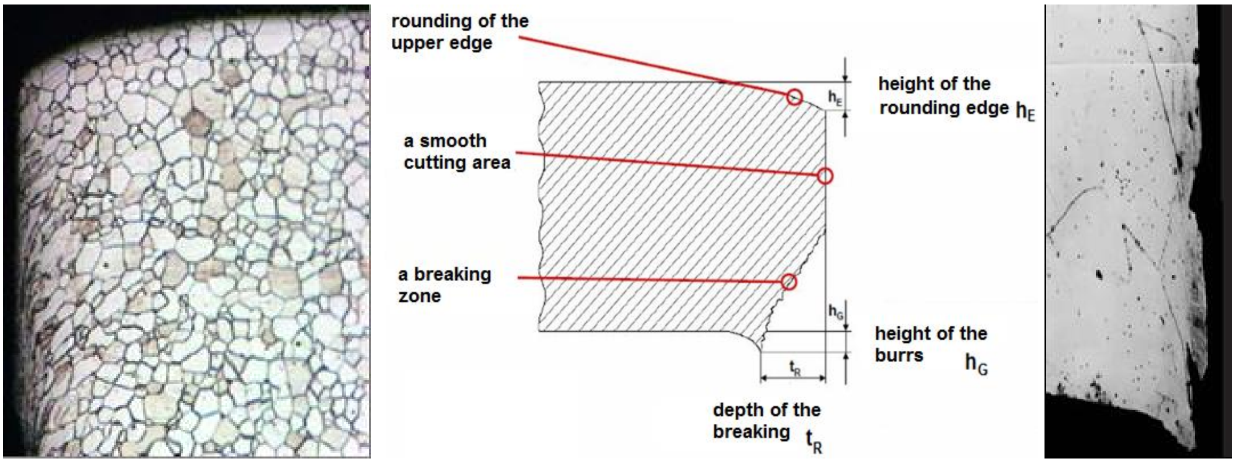

Fig. 2. Possible defects after punching of the lamellae [8].

- ✓ Distortion of varnish layers in the impact area that increases the losses from the eddy currents;
- ✓ Structural changes in the area of mechanical impact after the punching process of the material – see Fig. 2;
- ✓ Pollution of an environment area from the use of a cooling lubricant liquid to increase the wear resistance of the punch;
- ✓ One of the noisily production when used an automatic presses from 600 to 1 200 hits/min.

The appearance of the laser technology in the recent years is related with a number of advantages [9–11] that make it much more needed and affirmative in the industrial production for cutting of sheet material:

- — A contactless cutting process – there is no wear of the tool;
- — Processing of details with a complex configuration;
- — A rapid implementation of new design solutions to shorten time for testing the new model and to produce some prototypes;
- — Low production costs and high performance (it not required manufacturing of another punching tool for each new design idea);
- — A good quality (there are no burrs, with a small HAZ, etc.).

The correct selection of the technological parameters for production of lamellae is connected with the knowledge of the criteria for evaluating quality of the cuts (Fig. 3) [12, 13].

From the large set of factors that affect an influence on the complex process of laser beam interaction with the substrate of the material, it could be separated two major factors which have significant importance as well as the very operation of the process and processing quality. These are the power density in the irradiated area and the reaction time [14, 15].

For a given diameter d of working spot the power density q_s of laser beam is related with the output laser power P

$$q_s = \frac{4P}{\pi d^2} \tag{1}$$

In turn, cutting speed v as one of the most important technological parameter of laser cutting process through melt [16, 17] is connected with reaction time t of the laser beam in the irradiated area

$$t = d/v \tag{2}$$

Only in a certain combination between these two technological parameters: laser power and cutting speed (respectively laser power density and reaction time) can be maintained an optimum operation mode of the laser cutting process by melting for given material. The requirement is in the irradiated area to maintain the operating temperature in the range between that of the melting point T_m and evaporation T_v for the sheet material of electrical steel

$$T_m \leq T \leq T_v \tag{3}$$

Experimental investigations

Laser sources with different technological parameters are produced globally, but some of them are suitable for realizing of cutting process by melting of thin sheet material of electrical steel. That is why the process quality and its economic efficiency are directly

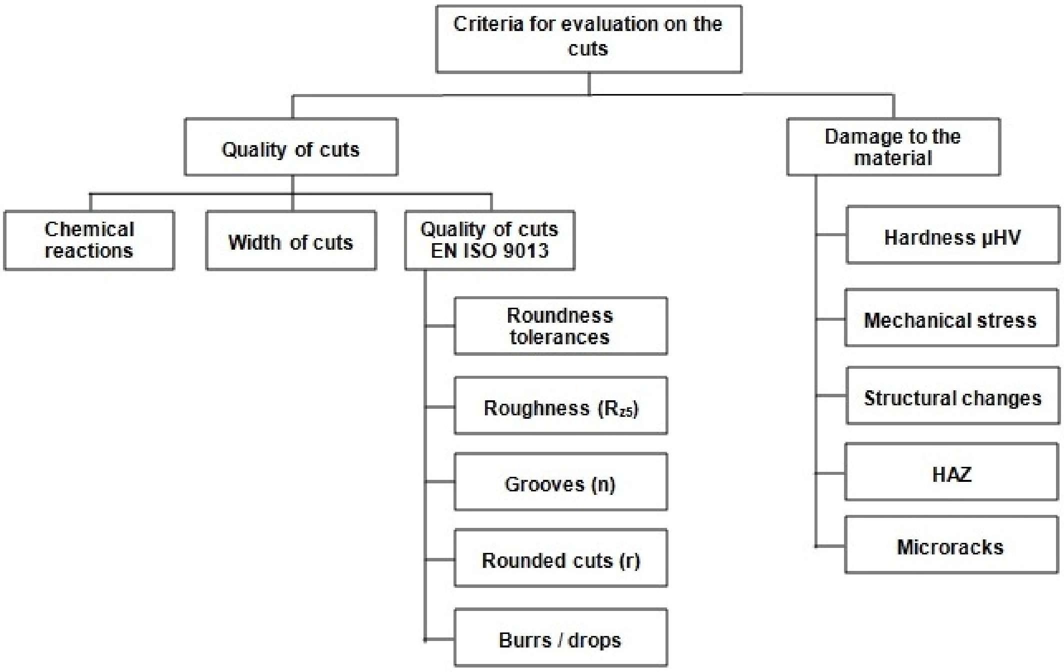

Fig. 3. An overview of a schema that include the cutting quality criteria [18].

related with the choice of a suitable laser cutting system.

The experimental investigations were made on industrial laser technological system TruLaser 1030 [19] with dimensions of working range 3000 × 1500 × 75 mm, consumption power 35 kW, maximum cutting speed 80 m/min, focal length of the optical system 200 mm, maximum pressure of the working gas (nitrogen) 20 bar. Technological parameters of the laser sources: wavelength 1.03 μm, maximum frequency of following pulses 20 kHz, maximum laser power 2 kW, minimum diameter of working spot 0.200 mm, beam quality BPP = 4 mm.mrad.

The choice of disk laser TruDisk 2001 (wavelength 1030 nm) to perform the experiments conducted in our research on the laser cutting of lamellae by electrical steel with 0.35 mm and 0.50 mm thickness, is determined through the following considirations:

- High efficiency – 30%;
- A possibility for a transport the laser beam through fiber to the cutting area;
- High-speed cutting;
- Low maintenance and running costs;
- A stable quality of the laser beam parameters during the running;
- High productivity.

The investigations are grouped in several experimental series and accordingly is changing laser power P and $v = \text{const}$ or vice versa the velocity is a variable in a given operating range, but $P = \text{const}$.

For each group of experiments was monitored for a width of input b_{input} and the width of output b_{output} of the cuts – parameters connected with the treatment quality. Dependencies that investigated are:

— $b_{\text{input}} = b_{\text{input}}(P)$ and $b_{\text{input}} = b_{\text{input}}(v)$;

— $b_{\text{output}} = b_{\text{output}}(P)$ and $b_{\text{output}} = b_{\text{output}}(v)$,

as the observations and measurements were made using a microscope Neophot with a magnification to 2000.

Experimental results

Investigating the influence to the change of laser power P under constant cutting velocity v. In that study the technological parameter laser power P varies in the range $P \in [400 \div 2000]$ W with step $\Delta P = 200$ W. During a realization of the technological cutting process remain constants a diameter of a gas nozzle (1.7 mm) and the pressure of nitrogen gas (14 bar).

The experiments are conducted in four groups as in each one of them the cutting velocity is supported constant: 4 m/min, 8 m/min, 14 m/min, 20 m/min.

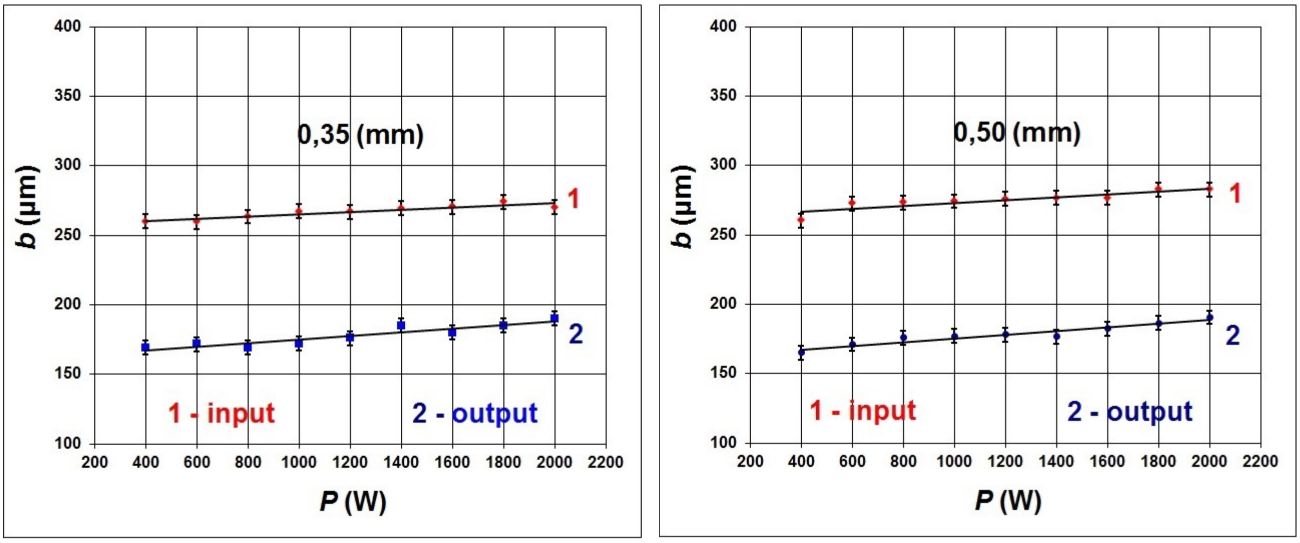

Fig. 4. Graphics of the experimental dependences $b_{\text{input}} = b_{\text{input}}(P)$ and $b_{\text{output}} = b_{\text{output}}(P)$ to the cutting process with velocity $v = 8$ m/min.

The results of changes on the cutting width in the input b_{input} and the output b_{output} as a function by variation of laser power P are graphical presented on Fig. 4.

Analogous graphical dependences have been seen in the experiments for which v is supported constant respectively 4 m/min, 14 m/min, 20 m/min.

Fig. 5 shows graphical relationships of $b_{\text{input}} = b_{\text{input}}(P)$ for cutting of samples with both thickness of steels to cutting velocity $v = 20$ m/min and focus position $\Delta f = -2.00$ mm.

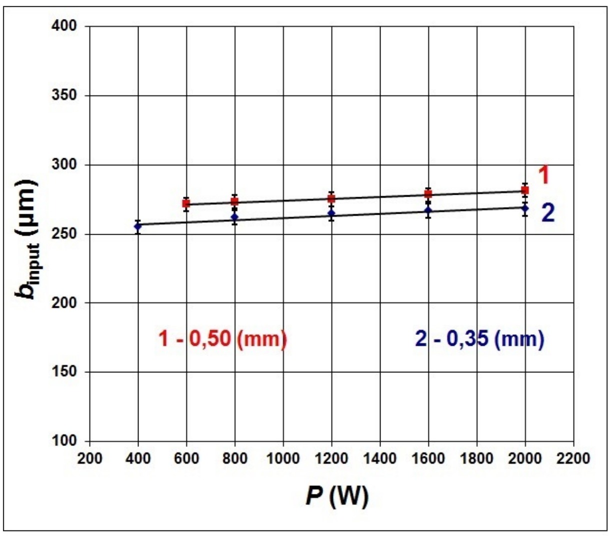

Fig. 5. Graphics of the experimental relationship $b_{\text{input}} = b_{\text{input}}(P)$.

By the analysis of the obtained experimental investigations can be made the following conclusions:

- ✓ The rapidity of which is being varied the cutting width as well as to the input Δb_{input} and the output Δb_{output} in a function of the studied power P have slight values, respectively on the input $\Delta b_{\text{input}}/\Delta P = 0.0081$ μm/W; on the output $\Delta b_{\text{output}}/\Delta P = 0.0061$ μm/W. The amendment of cutting width Δb_{input} and Δb_{output} in studied range of laser power P for both thickness steels is on the order of ± 5 μm.
- ✓ The change of the power of laser radiation in the studied range $P \in [400 \div 2000]$ W does not lead to significant variance in the cutting width b both the input and the output, i.e. the geometry of the cuts.

Investigating the variation of the cutting velocity v under constant laser power P. During the experiments the cutting velocity v varies in the interval $v \in [20 \div 60]$ m/min by step $\Delta v = 10$ m/min. All the rest technological parameters that have already been given up stand constant, as for each one series of experiments the laser power P is respectively: 500 W, 1000 W, 2000 W.

The results of experiments when studying the relationships $b_{\text{input}} = b_{\text{input}}(v)$ and $b_{\text{output}} = b_{\text{output}}(v)$ are given in graphical aspect. In Fig. 6 are shown the graphics of this study with the experiments of constant power of laser radiation $P = 2000$ W for cutting of lamellae with thickness 0.35 mm and 0.50 mm from the electrical steel.

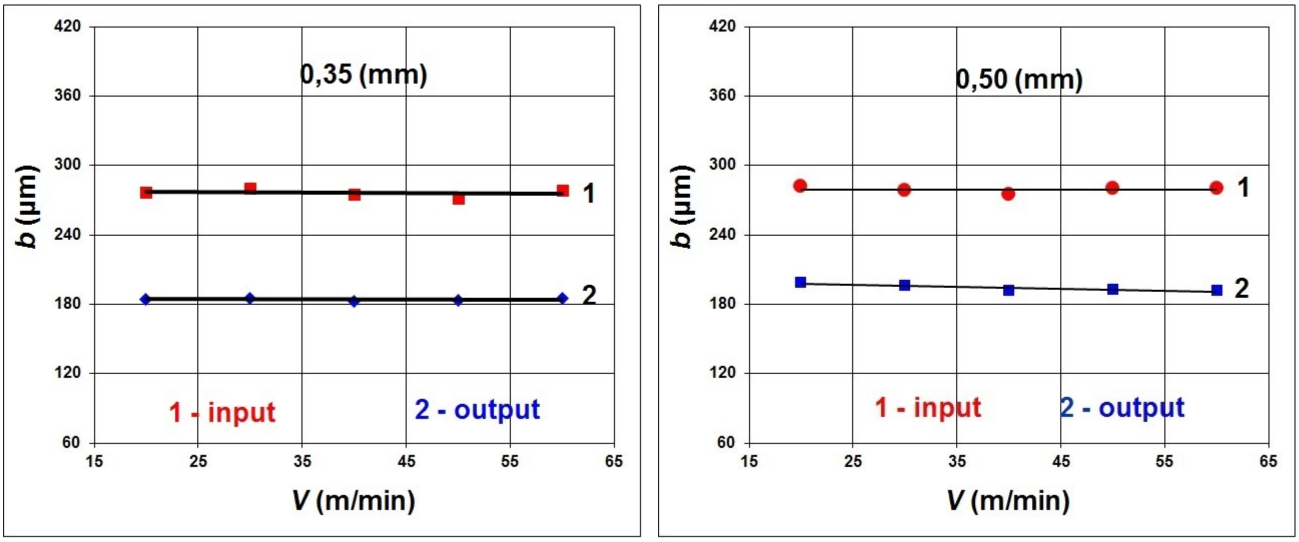

Fig. 6. Graphics of the relationships $b_{input} = b_{input}(v)$ and $b_{output} = b_{output}(v)$ to cutting of samples by electrical steel.

Analogous results of the dependencies $b_{input} = b_{input}(v)$ and $b_{output} = b_{output}(v)$ are obtained in the other two series of experimental studies: $P = 500$ W and $P = 1000$ W.

For the assessment the thickness of sheet material on the results of cutting process, some experiments were carried out on the samples with thickness 350 μm and 500 μm to the same process parameters. The results of the investigation are shown on Fig. 7.

By the analysis of the obtained results can be made the following conclusions:

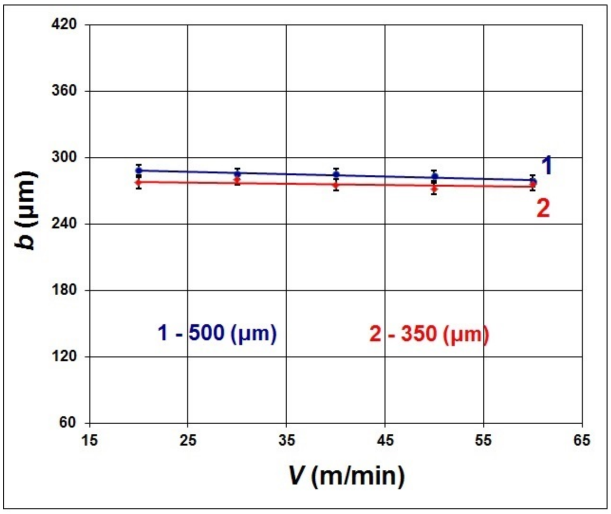

Fig. 7. Experimental dependence $b_{input} = b_{input}(v)$ throughout the same focus position $\Delta f = -2.00$ mm.

- ✓ The change of the cutting velocity v in the range $(20 \div 60)$ m/min with the step 10 m/min leads to no variation in the cutting width b as well as on both input and output. Average values of the cutting width b in the studied interval of speeds are as follows:
  - For 0.35 mm thickness – $b_{input} = (262 \pm 5)$ μm; $b_{output} = (173 \pm 5)$ μm;
  - For thickness of 0.50 mm – $b_{input} = (273 \pm 5)$ μm; $b_{output} = (186 \pm 5)$ μm.
- ✓ There is no significant change in the rapidity with which varies the cutting width Δb to the cutting velocity Δv for the both thickness of sheet steel (0.35 mm and 0.50 mm).

Microscopic analyzes. Using optical observations on the irradiated areas we evaluate the quality of cuts in the studied series experiments. There are defined limit values for the power P and cutting velocity v.

For example bending of the cutting edge and drops of molten material is ascertained on the output of the cuts obtained by cutting of samples with power of laser radiation $P = 1000$ W and velocities greater than 50 m/min, see photos on Fig. 8.

Accordingly, the visual observations showed good cuts in the interval of the laser power $P = 1000$–1400 W and cutting velocities 20 m/min – 40 m/min (Fig. 9).

Concerning the quality has been analyze and the heat affected zone with supporting of photos and optical observations, based on standard methods.

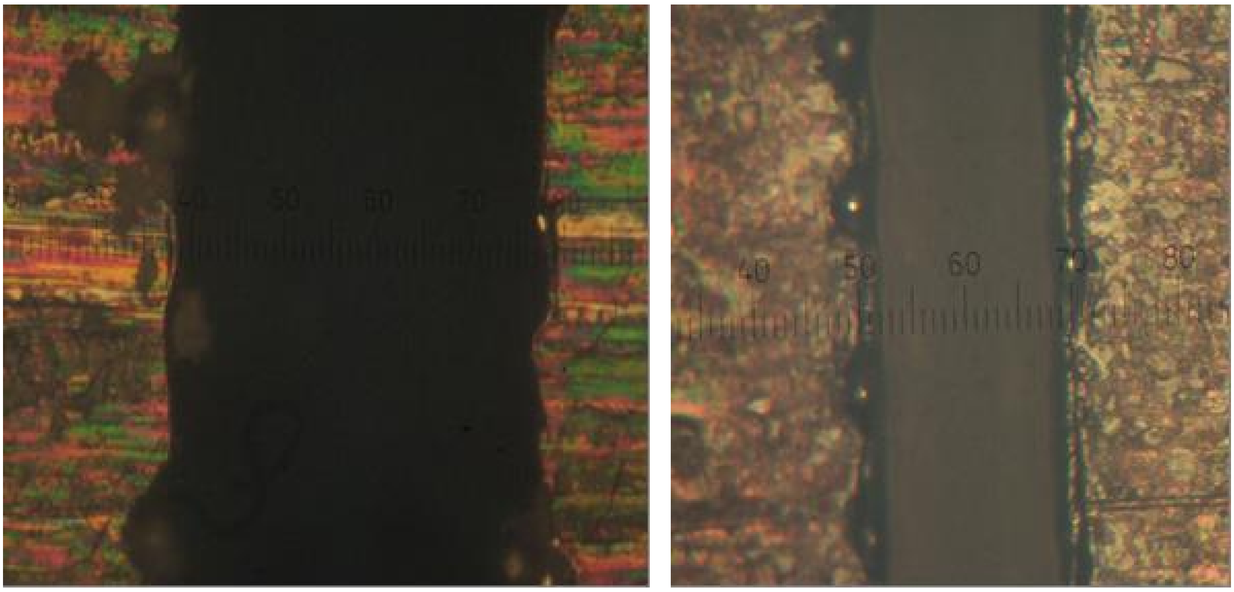

Fig. 8. Cutting parts in $P = 1000$ W of samples with thickness: a) 0.35 mm and $v = 60$ m/min; b) 0.50 mm and $v = 50$ m/min.

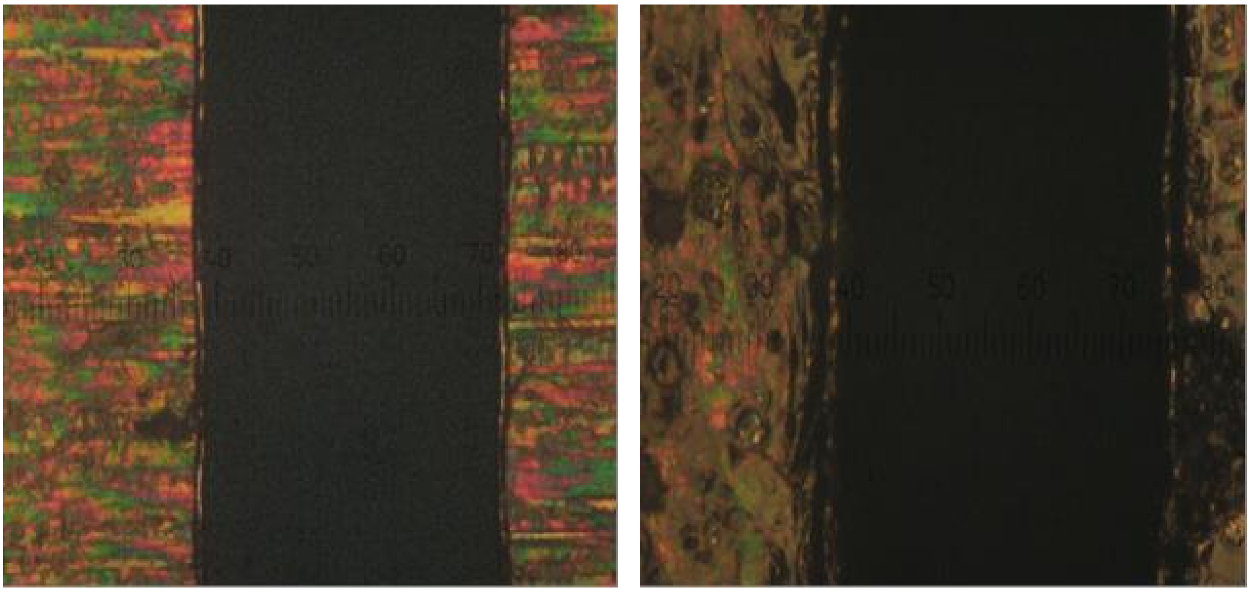

Fig. 9. Cutting parts of samples with thickness: a) 0.35 mm; b) 0.50 mm with $v = 20$ m/min in $P = 1200$ W.

In Fig. 9 are represented photos by that are being watched good cuts with laser power $P = 1200$ W and cutting velocity $v = 20$ m/min.

Summary. On based on to the received results by the experimental investigations of the influence of technological parameters: laser power P and cutting velocity v on the cutting quality determine their working intervals in which are realized laser cutting process by melting of lamellae with laser technological system TruLaser 1030 and disk laser TruDisk 2001 in good quality.

In terms of microscopic analysis and considerations of energy efficiency as advisable modes are defined the following intervals:

- For the power of laser radiation 1000 W – 1400 W;
- For the cutting velocity $v = (20 \div 40)$ m/min.

CONCLUSION

According to preliminary studies made by us we have reached a conclude that along with the considered two basic technological parameters (power P and velocity v) which exert influence upon the introducing of specific technology for laser cutting of lamellae through melting in the production of electric motors, it is necessary to make and other additional studies. By essential is to investigate the influence on the technological process from the gas pressure, the focus position toward the working surface, as well as the complexity to the contour of the lamella. These studies will be a subject of our next publications.

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ИЗСЛЕДВАНЕ НА ВЛИЯНИЕТО НА ТЕХНОЛОГИЧНИТЕ ПАРАМЕТРИ МОЩНОСТ И СКОРОСТ ПРИ ЛАЗЕРНО РЯЗАНЕ НА ЛАМЕЛИ

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(Резюме)

Непрекъснатото развитие на машиностроенето, автомобилостроенето, електротехниката и др. пораждат необходимостта от развитие на нови системи за електрозадвижвания. Основен модул в тях се явяват съвременните електромотори. Това, от своя страна, налага проектиране и тестване в кратки срокове на нови конструкции електромотори. Тези изисквания пораждат и потребността от търсене на нова технология при производство на ламели за статорните и роторни пакети на електродвигателите.

Докладът разглежда изследвания свързани с една нова иновативна технология за лазерно рязане чрез топене с шайбов лазер TruDisk 2001 на листов материал от електротехническа стомана. Дискутира се влиянието на мощността *P* на лазерното лъчение и скоростта *v* на рязане за получаване на качествени срезове. На базата на редица експериментални изследвания са определени и изведени препоръчителни работни интервали за рязане на листов материал с дебелини 0,35 mm и 0,50 mm.