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# INFLUENCE OF CUTTING PARAMETERS ON HEAT-AFFECTED ZONE AFTER LASER CUTTING

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Original scientific paper
The article deals with a method of thermal cutting of materials, specifically with laser technology. The theoretical part describes its principles, capabilities and use of laser in the process of machining, mainly the procedure of cutting material using a laser beam. The experimental part is focused on cutting the cobalt alloy by a continuous $CO_2$ laser and the influence of technological parameters during cutting on the final quality of the cutting area. Suitable technological parameters were determined on the basis of metallographic analysis, and the lowest heat influence on the material was achieved.

**Keywords:** *heat-affected zone (HAZ), laser cutting, laser parameter, machining*

### Utjecaj parametara rezanja na zonu utjecaja topline nakon laserskog rezanja

Izvorni znanstveni članak
Članak se bavi metodom toplinskog rezanja materijala, posebice laserskom tehnologijom. U teorijskom dijelu opisan je njezin princip, mogućnosti i uporaba lasera u procesu obrade odvajanjem čestica; uglavnom postupak rezanja materijala uporabom laserskog snopa. Eksperimentalni dio usredotočen je na rezanje kobaltne legure pomoću neprekidnog lasera $CO_2$ i utjecaj tehnoloških parametara tijekom rezanja na završnu kvalitetu područja rezanja. Na temelju metalografske analize utvrđeni su pogodni tehnološki parametri i postignut najniži utjecaj topline na materijal.

**Ključne riječi:** *laserski parametar, lasersko rezanje, obrada odvajanjem čestica, zona utjecaja topline (ZUT)*

## 1 Introduction

Although the development of laser from historical viewpoint was very slow, today we are directly or indirectly accompanied by lasers on a day to day basis. In 1917, Albert Einstein began by describing theoretical foundations of simulated emission of radiation. He drew attention to the possible existence of spontaneous, but also stimulated emission. Facilities that generate and amplify electromagnetic radiation on the principle of stimulated emission of radiation, marked with the Maser symbol, were constructed as late as the mid 20$^{th}$ century. About 10 years later, Theodore H. Maiman formed the first working LASER (Light Amplification by Stimulated Emission of Radiation) in the U.S.A. Since then, the development of laser has come a long way (of changes, progress) and laser has started (technology of generation and amplification of electromagnetic radiation has started) to penetrate into various areas of science and human activities [1].

## 2 Laser principle

The quality of surface needs to be understood as an integral characteristic of a machine part. Laser is a device that emits light through a process of optical amplification based on the stimulated emission of photons. During the stimulated emission (Fig.1), a photon meets an excited atom or molecule and stimulates the electron to pass into the low energy level. Here, it transmits another photon. However, the prerequisite is that the incoming photon should have the energy required for this process. It is said to have the required energy when this energy corresponds to the difference in energy between the excited level and the lower level [7].

After the stimulated emission, the new photon has exactly the same frequency and the same phase position as the first photon and moves in the same direction. The light beam has increased. Where there was only one photon previously, two of the same kinds are on route now. If these photons meet the excited atoms again, they generate more photons and the light beam increases further [7].

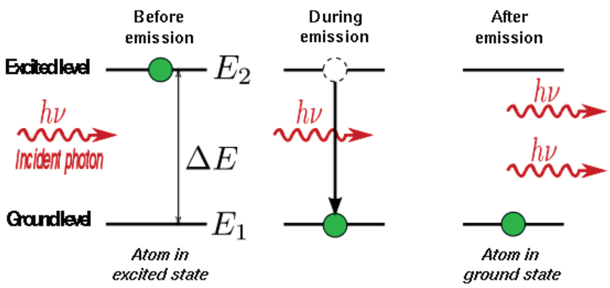


**Figure 1** Stimulated emission [6]

Bunch of laser beams is the source with high density of energy, the radiation comes from laser in the form of little spread, monochromatic (single wavelength) beam and coherent electromagnetic waves in a wide range of wavelengths from the ultraviolet through visible light, infrared region further to the border of millimeter waves [4].

## 3 Laser cutting technology

Placing the laser beam during machining is one of the most progressive methods, which is slowly replacing conventional machining technologies. Nowadays, due to its huge expansion, laser technology is the most frequent use of laser in industrial production. Technological use of laser mainly consists in machining and processing of materials, based on taking advantage of the ability of powerful lasers to concentrate optical energy radiation in space, in time and spectral interval and on the interaction of radiation with the material. Laser technology of cutting is the method of thermal parting of material with no material removal due to the use of mechanical work; it uses physical and chemical processes or the combination of both. As a result, only minimal deformations arise both in the process of division and after it has finished [2, 3].

The cutting process is based on the interaction of laser beam, cutting gas and cut material. It utilizes high concentration of the energy produced by laser radiation which enables to divide all technical materials, regardless of their thermal, physical and chemical properties; the division process is fast, which ensures high productivity. It is especially used for materials with low thermal conductivity. The effort is to evaporate the material as quickly as possible while maintaining the area affected by thermal effects as small as possible. This results in a high quality cutting edge. Cutting with laser has a wide range of uses for production on a small scale as well as for large-scale production in batches.

Laser cutting technology offers a major advantage in speed, quality and accuracy of burnouts; it achieves low manufacturing cost and minimizes the amount of waste, which is associated with the best possible use of the materials and energy [2, 3].

## 4 Experiment

Ever increasing demand for quality, durability and accuracy in the production of metal parts for aircraft and cremation turbine engines requires application of new materials. These are mainly products of stainless steel and special alloys (aluminium, nickel, cobalt and titanium). These new materials have high requirements for processing. Such material is Haynes 188 alloy used for our experiment.

The arrival of laser technology has enabled thermal cutting of virtually any type of material, including electrically non-conductive material and materials with extremely high affinity to oxygen or nitrogen. As an advanced technology, laser enables processing of materials difficult to weld, difficult to machine, high-strength or high-heat resistant materials, because in this case, mechanical properties of material, strength, hardness and toughness are not relevant.

### 4.1 Haynes 188 alloy

Haynes 188 alloy is a cobalt-nickel-chromium-tungsten alloy that combines excellent high temperature strength with very good resistance to oxidizing environments up to 1095 °C for prolonged exposures, and excellent resistance to sulphate deposit hot corrosion. It is readily fabricated and formed by conventional techniques, and it is used for cast components. Haynes 188 alloy has good forming and welding characteristics, but due to its strength and low thermal conductivity it is not easy to machine this alloy [8].

**Physical and mechanical properties:**

- density 8,98 g/cm$^3$
- melting range 1315 ÷ 1410 °C
- modulus 232 GPa
- tensile strength, $R_m$ 945 MPa
- yield strength, $R_e$ 465 MPa
- elongation 53 %.

**Chemical composition:**

- Co 39* %
- Ni 22 %
- Cr 22 %
- W 14 %
- Fe 3 %
- Mn 1,25%
- Si 0,35 %
- C 0,1 %
- La 0,03 %
- B 0,015* %.

* - max

### 4.2 Laser system

Cutting samples was carried out on a laser machine tool Delta Winbro. Delta can be configured with up to four different types of laser sources to meet the requirements of specific applications of laser technology (cutting, drilling, welding). For our purpose, a source Rofin DC 020 was used, which consists of Winbro Delta gas $CO_2$ laser operating in continuous mode (Fig. 2). 5-axis machines Winbro Delta system enable production of complicated parts with an accuracy of 0,015 mm and repeatability 0,010 mm [5].


**Figure 2** Laser system [5]

### 4.3 Laser system

Samples were cut from a 1,27-mm-thick sheet of the above-mentioned alloy. The cutting process was affected by setting particular laser performance parameters. These were cutting parameters, namely laser output performance and feed rate, which gradually changed during cutting as necessary and according to the achieved cut quality. Other parameters that also affect the quality of cutting were constant.

The values of output performance and cutting feed while cutting the samples were selected with regard to utilizing full capacity of laser. Gradually, the output performance was increased and the cutting machines speed was changed as necessary. Due to the increasing cutting speed during the experiment, more and more tricked slag in the form of burr began to appear at the bottom of the sample pieces.

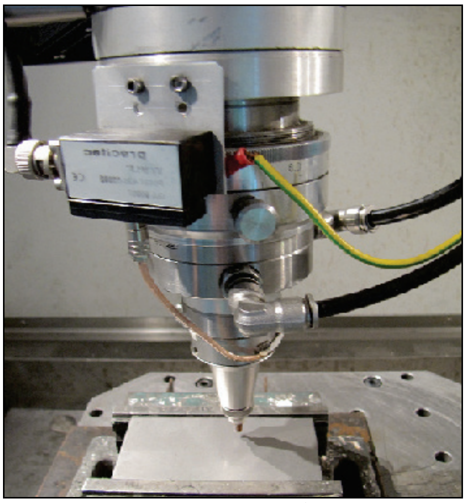

**Figure 3** Laser cutting

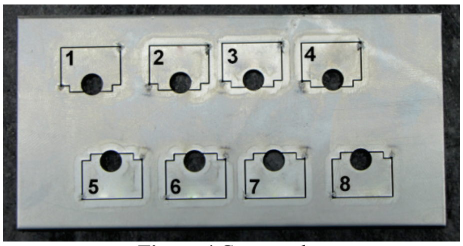


**Figure 4** Cut samples

On the contrary, high output performance and low feed rate resulted in heat-affected area at the cutting edge, which had an impact on the final quality. As we did not consider the size and amount of slag tricked to be an evaluation parameter, we opted for higher feed rate with increasing output performance. In this way, 30 samples were gradually created (Fig. 4).

## 5 Measurement and evaluation

For measurement and evaluation of the width of the heat-affected area of the samples it was necessary to carry out metallographic analysis. The samples were embedded into tablets (Fig. 5), ground, polished and etched to the selected etching agent.

After reaching the specular gloss and visibility of individual structural components, individual surfaces were observed through a light microscope. The purpose was to determine the macroscopic nature of the cut surface by observing several times (20×) enlarged sample.

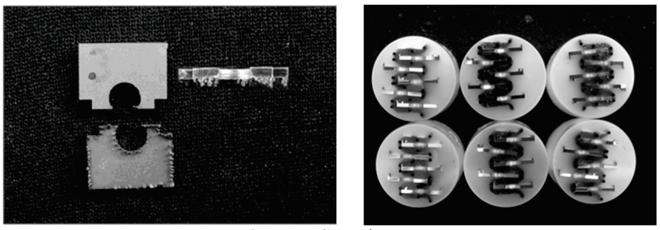

**Figure 5** Samples

The essence of the evaluation was to find suitable performance parameters during laser machining of alloy HS 188. The aim was to achieve the best possible cutting surfaces with different combination of values of output performance and feed rate with respect to the full potential of the laser. Due to the large number of samples and the amount of the processed data in the evaluation, samples that represent working range of laser parameters were selected on the basis of visual inspection of quality of cutting, see Tab. 1.

**Table 1** Cutting parameters for sample No. 1

| Performance parameters of the machine | | Process parameters of the machine | |
|---|---|---|---|
| Output performance / W | 600 | Jet distance / mm | 0,9 |
| Feed rate / mm/min | 700 | Pressure of assistance gas / MPa | 1,2 |
| Excitation frequency sources / Hz | 5000 | Focus position / mm | 1,9 |

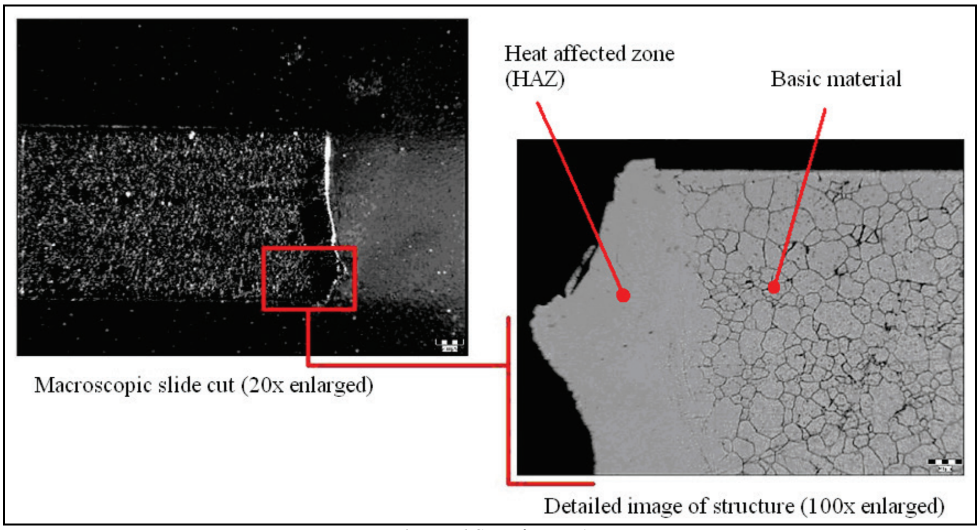


**Figure 6** Sample No. 1

**Table 2** Cutting parameters for sample No. 2

| Performance parameters of the machine | | Process parameters of the machine | |
|---|---|---|---|
| Output performance / W | 800 | Jet distance / mm | 0,9 |
| Feed rate / mm/min | 3000 | Pressure of assistance gas / MPa | 1,2 |
| Excitaction frequency sources / Hz | 5000 | Focus position / mm | 1,9 |

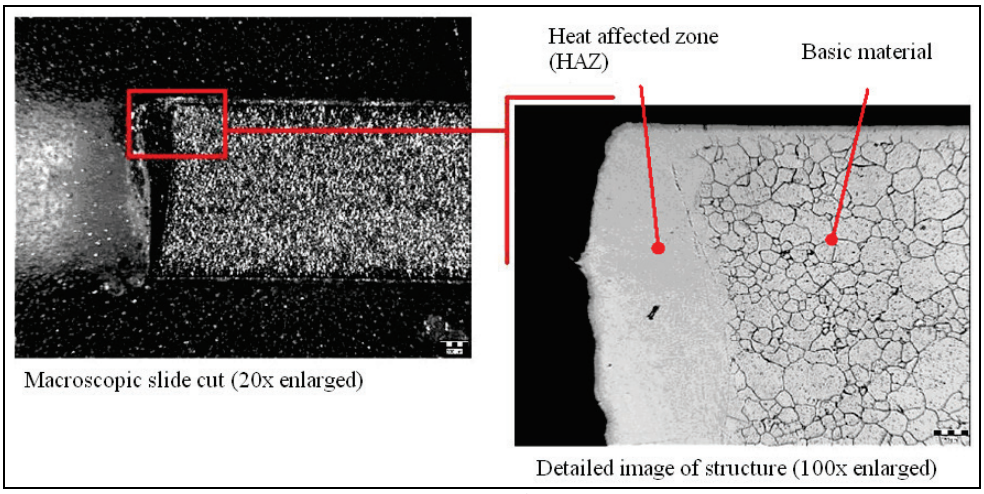


**Figure 7** Sample No. 2

**Table 3** Cutting parameters for sample No. 3

| Performance parameters of the machine | | Process parameters of the machine | |
|---|---|---|---|
| Output performance / W | 1800 | Jet distance / mm | 0,9 |
| Feed rate / mm/min | 1000 | Pressure of assistance gas / MPa | 1,2 |
| Excitaction frequency sources / Hz | 5000 | Focus position / mm | 1,9 |

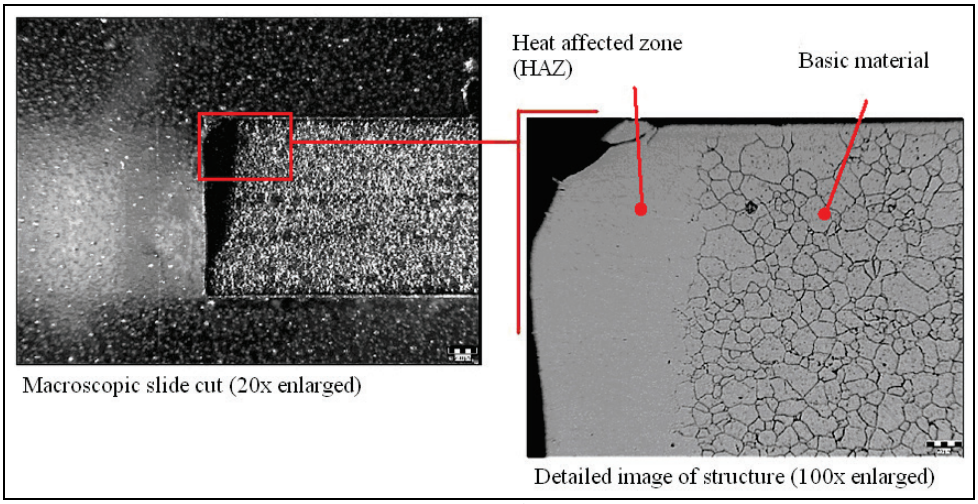


**Figure 8** Sample No. 3

**Table 4** Cutting parameters for sample No. 4

| Performance parameters of the machine | | Process parameters of the machine | |
|---|---|---|---|
| Output performance / W | 1800 | Jet distance / mm | 0,9 |
| Feed rate / mm/min | 3000 | Pressure of assistance gas / MPa | 1,2 |
| Excitaction frequency sources / Hz | 5000 | Focus position / mm | 1,9 |

On the images obtained in the area of laser cutting, heat-affected zone (hereinafter HAZ) is clearly visible. According to the theoretical assumption, HAZ width ranges depend on the parameters of cutting tools, especially on the speed of laser beam displacement. Therefore, the HAZ width was studied depending on this quantity. HAZ was created by short but very intense action of the thermal energy of laser beam. In some ways, HAZ features change in structure and material properties, which is undesirable. It can come to turbidity, accompanied by increased hardness and brittleness, the occurrence of crevices. When selecting the appropriate parameters, the remelted layer size and HAZ can be influenced to some extent, but their occurrence cannot be completely eliminated. Increasing feed rate during cutting should ensure that there is not enough time for the basic material in the cut to warm up. Thus, the total amount of heat input into the cutting area will be smaller, resulting in smaller HAZ. Since the HAZ width is irregular for all cuts, individual samples were collected at places with the highest impact of heat on the material. Higher values were always achieved in the upper section, whose width was subsequently measured, see Fig. 11.

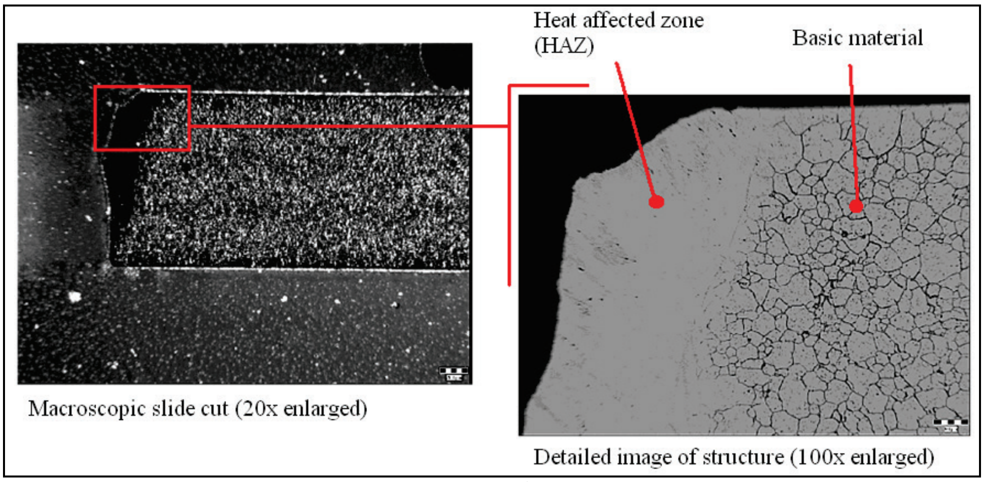


**Figure 9** Sample No. 4

**Table 5** Cutting parameters for sample No. 5

| Performance parameters of the machine | | Process parameters of the machine | |
|---|---|---|---|
| Output performance/ W | 1800 | Jet distance / mm | 0,9 |
| Feed rate / mm/min | 5000 | Pressure of assistance gas / MPa | 1,2 |
| Excitation frequency sources / Hz | 5000 | Focus position / mm | 1,9 |

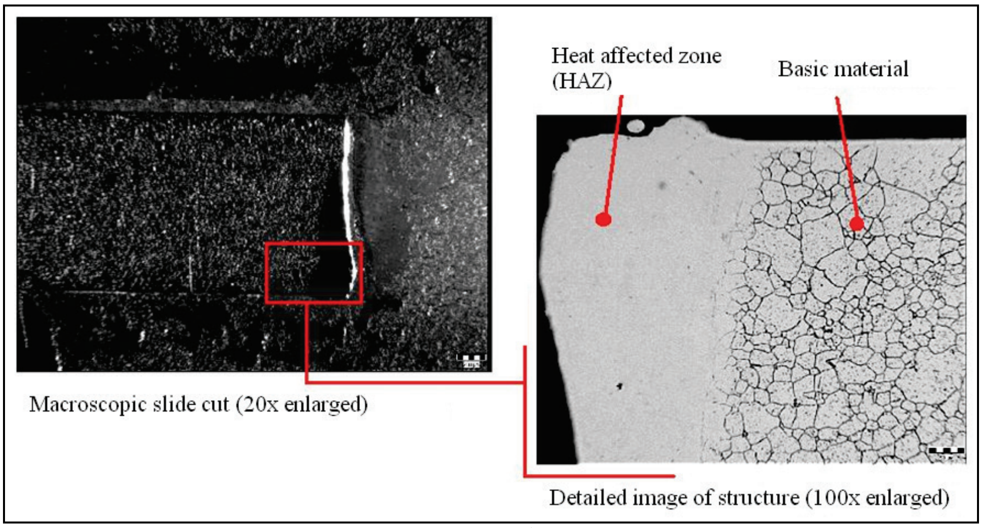


**Figure 10** Sample No. 5

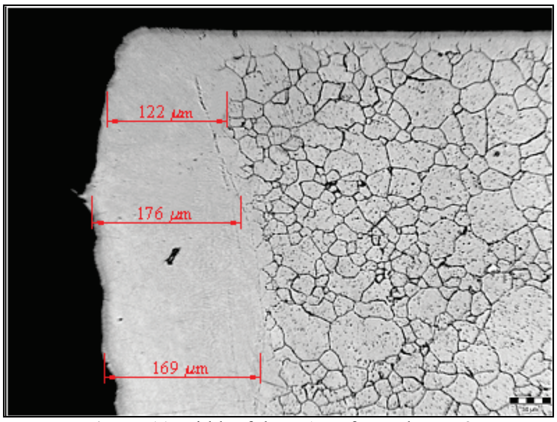


**Figure 11** Width of the HAZ of sample No. 2

The measured values of the width HAZ ranged from 122 to 293 μm for the samples. The smallest width HAZ, where the maximum width value does not exceed 176 μm, was achieved in sample No. 2, the cut was made with output performance of 800 W and feed rate of 3000 mm/min. In contrast, the largest thermal influence on the material occurred in sample No. 5, where the output performance was 1800 W and 5000 mm/min speed. Although the evaluation was used in only five samples, the course of the experiment showed an indirect dependence of HAZ width on the feed rate. It can be stated that when using a continuous $CO_2$ laser, the extent of thermal influence on the material does not depend only on the feed rate, but also on other factors.

## 6 Conclusion

The study was focused on using laser technology in machining. This technology has been increasingly applied and developed. This is due to increasing demands for the production quality, durability and precision and the need for new applications of machined materials. For these so-called special alloys, there is a significant decrease in their machinability, therefore conventional cutting operation is often replaced by non-conventional machining technology. Laser technology is currently one of the most progressive technologies and recently it has been passing through incredible boom in mechanical engineering.

The article does not only deal with well-known facts, but also tries to determine the possible influence of processing parameters, especially the output performance and the feed rate on the quality of cutting surface. In the course of the experiment, the width of the thermal influence on the material was observed, where there was no evidence of direct dependence on feed rate. Therefore, the evaluation shows that appropriately selected combination of performance parameters of laser can lead to very good results with regard to the quality of the cutting surface as well as the size of the heat-affected zone.

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## 7 References

[1] Benko, B. et al. Laserové technologie. 1. vyd. Bratislava: STU Bratislava, 2000, p. 122. ISBN 80-227-1425-9.
[2] Maňková, I. Progresívne technologie. Technická univerzita Košice, Strojnická fakulta, Košice, Edícia vedeckej a odbornej literátury, Vienala, 2000, p. 270, ISBN 80-7099-430-4.
[3] Šulc, J. Průmyslové aplikace laserových systémů [online]. 2004. http://www.plslaser.cz/pdf/prumysl.pdf (07.10.2011).
[4] ČEZ (online). Lasery kolem nás. http://www.cez.cz/edee/content/microsites/laser/laser.htm. (05.02.2011.).
[5] Winbro Group Technologies (online). 2008. Systems Delta. http://www.winbrogroup.com/systems/delta.php. (03.04.2011.).
[6] En.wikipedia.org [online]. 2005. Stimulated emission. http://en.wikipedia.org/wiki/Stimulated_emission. (03.10.2011).
[7] The laser as a tool: Technical information [online]. TRUMPF GROUP 2007. http://www.trumpf.com/en/innovation/ (10.10.2011).
[8] Haynes International, Inc. (online). 2001. High Temperature alloys. http://www.haynesintl.com/pdf/h3001.pdf. (05.10.2011).

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