**Experimentální Analýza Napětí 2001**
Experimental Stress Analysis 2001
**39th International Conference**
June 4 - 6 , 2001 Tábor, Czech Republic

# Nd:YAG PULSED LASER CUTTING OF METALS

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***Abstract**: Pulsed Nd:YAG laser KLS 246 – 102 with average power 150W was developed for cutting, drilling and welding of metal and non -metal materials with thickness up to 2 mm* [1]. *The universality of this system is achieved by the movable back mirror of the laser resonator, that determine quality of the output laser beam Instead of $CO_2$ laser with a wavelength 10,6µm, with Nd:YAG laser and its wavelength 1,06µm is possible to cut aluminium and cooper.*

*We chose an usually used kind of metal, steel (class 11) to test the optimal cutting conditions on various thickness from 0,1 to 1 mm. Each thickness was cut and drilled with increasing energy values and decreasing values of pulse frequency and travel speed. Nitrogen was used as a protection gas with pressure from 3 to 8 bar.*

*The goal of our experiment is to find optimal laser parameters for cutting steel of each thickness. A common dependence of travel speed, frequency and energy on thickness of material was verified. The results will be are summarised into application tables for laser software.*

**Key words:** Nd:YAG laser, cutting, metal, speed, pulse energy

## 1. INTRODUCTION

Two kinds of laser, that emitted radiation in the infrared spectral range, are used in the industrial treatment of materials, gaseous $CO_2$ laser (10,6 µm) and solid state Nd:YAG (1,06 µm). Difference between them in the wavelength, charging efficiency and method of beam delivery to a work piece determines their exploitation in some specify production ranges. $CO_2$ lasers with higher efficiency 30% and higher depth of focus are able to cut low-carbon steel to 16 mm in thickness with continual power 2000 W. Quality of the cut is significantly dependent on the alignment of mirrors and lenses in beam delivery system. Nd:YAG lasers are charged by a krypton flash lamp and have lower efficiency then $CO_2$ laser, only 3%. Using a laser diode as a charging supply can increase it to 20 – 30 %. Nd:YAG laser beam can be focused to spot with diameter up to 0,03 mm, fine cutting and drilling of thin materials is possible. The main advantage of Nd:YAG laser is the possibility to deliver a beam by the flexible optical fibre into processing head, that can be fixed to machine tool. The optimal result of laser treatment is also dependent on the right setting of working parameters: i.e. power, beam diameter, travel speed, in case of pulsed laser also pulse length and frequency. Approximate values, recommended by a producer, is necessary to make more accurate in own experiment.

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# 2. LASER SYSTEM KLS 246-102

Laser system KLS 246 –102 made in firm LASAG AG, Switzerland is determined for cutting, drilling and welding up to 2 mm (fig.1. and fig.2). Technical data are introduced in table 1.

| average power | pulse length | max. energy | max. pulse power | frequency | Charging Voltage |
|---|---|---|---|---|---|
| 150 W | 0,1 – 20 ms | 30 J | 6 kW | 0,1 –1000 Hz | 150 – 400 V |

Table 1 : laser KLS 246 –102 – specification

System has a movable and changeable back mirror holder. Distance from the cavity can be changed from 190 up to 390 mm, three types of plane and spherical mirrors can be used. We obtain five resonators with different values of the product of beam radius and its half-angle divergence (BPP – beam parameter product), from 4 up to 24 mm.mrad [2],[3]. BPP determines laser beam radius after focusing by the lens in a processing head:

$$r_{foc} = f \,.\, BPP / M \,.r_o \qquad (1)$$

Where f is focus length of lens, M is magnification of the beam expander, $r_o$ is radius of input beam to lens. Lens with f = 50 – 75 mm is suitable for thin materials and marking, for thicker materials is necessary to use lens with f = 100 –300 mm, Because depth of focus, i.e. range, where laser beam has sufficient energy to vaporise material, increases with focus length. Laser energy is set by means of charging voltage on flash lamp. Energy of the pulse is proportional to the pulse length, lengths of 0,15 – 1 ms are used in a combination with high frequency to drilling and cutting, longer pulses up to 20 ms are suitable for welding. Maximal value of the frequency $f_{max}$ exists for each value of energy to not overgrow maximal the average power of laser $P_{max}$ :

$$P_{max} = E \,.\, f_{max} \qquad (2)$$

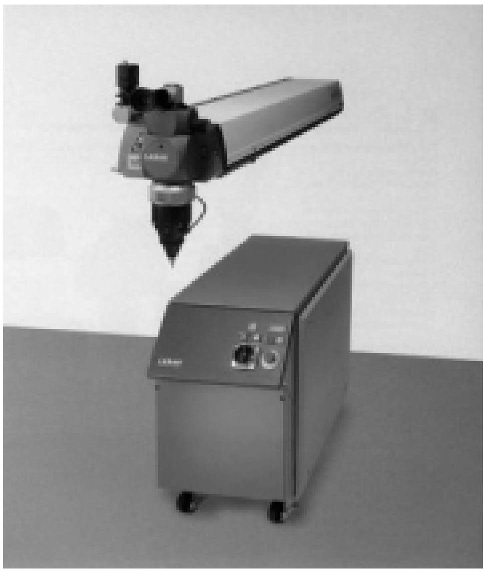


Fig.1: Laser KLS 246-102

Fig. 2 : Resonator with cavity

It is necessary to protect optic elements in processing head and remove melted material from beam path during the laser treatment. This is a function of the protected gas that is conducted from bottles to nozzle on the end of processing head. Oxygen, nitrogen, argon, helium or compressed air of the pressure up to 20 bars is used according to kind of application. Important part of a laser system is the position system for fitting and motion of the work piece. This is realised by means of the X-Y-Z table with servomotors connected with computer. The result cut quality is dependent, behind laser parameters, also on chosen cutting speed. Each material and each its thickness has own optimal speed, that must be at first calculated and than verified in experiment.

## 3. EXPERIMENT

The goal of our experiment was to create technologic tables for the software that controls laser and positioning system. The first tested material was steel (class 11), samples of thickness 0.1 mm, 0.2 mm, 0.6 mm, 0,8 mm a 1 mm were cut. Resonator for cutting with the plane back mirror in 390 mm distance from cavity emits beam with diameter 0.2 mm and maximal average power 48 W. Pressure of nitrogen was 5 bar. For approximate calculation of the cutting speed is possible to use equation for a heat and energy. The laser energy is equal to sum of energy, necessary to vaporise material in cutting joint [4]:

$$\rho \quad V\,(c\Delta T + L_v) + Q_l = (1\text{-}R)\ P.t \qquad (3)$$

Where $\rho$ is density, V volume and c specific heat of vaporised material, $\Delta T$ difference between vaporisation and normal temperature, $L_v$ is latent heat of vaporisation, $Q_l$ are heat losses, R is surface reflexivity, P.t laser energy. Volume V is product of beam diameter $D_{foc}$, cut depth h and cut length x. The equation for speed in mm/s, D = 0,2 mm, P = 48 W is derived from eq.3, for steel [5]:

$$v = 3{,}6\ (1\text{-}R) / h \qquad (4)$$

R is reflexivity that is direct dependent on temperature. It changes from 0,9 for normal temperature to zero for vaporisation. We estimate minimal speed with R = 0.5, (value verified in praxis), and maximal speed with R = 0.2. In case of pulsed lasers, minimal frequency has to ensure, that two neighbour spots of laser beam on material surface will overlap of 60 – 80 %, according a material thickness [6]:

$$f_{min} = 2v / D_{foc} \qquad (5)$$

Maximal average power was divided by frequency to calculate energy in one pulse. This energy is set by means of charging voltage and pulse length. Calculated predicted values are introduced in table 2 :

| **h (mm)** | **v (mm/s)** | **$f_{min}$ (Hz)** | **E (J)** | **t(ms)** |
|---|---|---|---|---|
| 0,1 | 14,4 – 29 | 144 – 290 | 0,26 – 0,15 | 0,15 |
| 0,2 | 7,2 – 14 | 72 – 140 | 0,5 – 0,3 | 0,2 |
| 0,6 | 2,4 – 4,8 | 24 – 48 | 1,6 – 0,96 | 0,2 |
| 0,8 | 1,8 – 3,6 | 18 – 36 | 2 – 1,2 | 0,3 |
| 1,0 | 1,4 – 2,8 | 14 – 28 | 2,6 – 1,6 | 0,3 |

Table 2 : Predicted cutting parameters

These parameters were used to the first examination of cutting, from which we derived following conclusions:

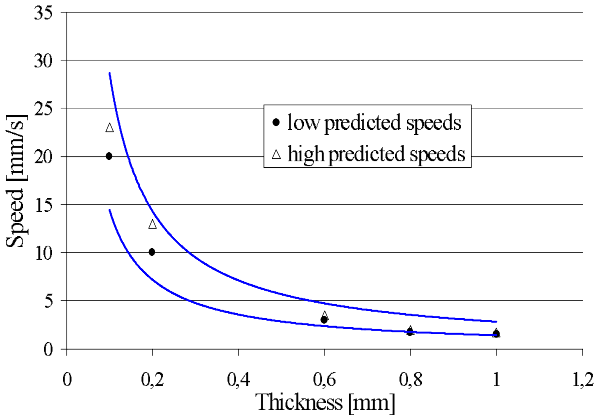
a) Optimal cutting speed for thin samples 0,1 and 0,2 mm is closed to maximal predicted value, with increasing material thickness speed shifts to the predicted minimum, because heat losses to volume are greater and the power density decreases with square of depth. Thickness 1 mm is impossible to be quality cut with power 45 W. We must prepare other experiment for thicker materials with higher power, that is possible with fibre optics and higher gas pressure. Fibre can be used only with standard resonator, where value of maximal power 150 W.
b) Optimal cutting frequencies are 200 - 50 Hz
c) Optimal pulse lengths for materials up to 1 mm are 0,2 ms and 0,3 ms.
d) The position of the beam focus in material was found as another important parameter. The focus lies on sample surface in case of thin materials to 0,2 mm, in thicker materials it is moved to half of material depth. Any out-of-flatness of metal sheet causes a non-uniformity cut. Some laser heads has control system for keeping constant distance between gas nozzle and material surface.

Each steel sample was cut with the restricted parameters and increased row of speeds:

| **h (mm)** | **v1** | **v2** | **v3** | **v4** | **v5** | **v6** | **v7** | **v8** | **$f_{min}$ (Hz)** | **E (J)** | **t(ms)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | (mm/s) | | | | | | | | | | |
| 0,1 | 8 | 10 | 15 | 18 | 20 | 23 | 26 | 29 | 300 | 0,15 | 0,15 |
| 0,2 | 4 | 5 | 7 | 9 | 10 | 13 | 16 | 19 | 200 | 0,22 | 0,2 |
| 0,6 | 2 | 2,5 | 3 | 3,5 | 4 | 6 | 8 | * | 100 | 0,45 | 0,3 |
| 0,8 | 1,5 | 1,75 | 2 | 2,25 | 2,5 | 3 | * | * | 70 | 0,65 | 0,3 |
| 1,0 | 1 | 1,5 | 1,75 | 2 | 2,5 | * | * | * | 50 | 0,96 | 0,3 |

Table 3: Tested cutting speeds

Optimal speeds are marked. In these cases we obtain cuts with smooth bottom sides without scales. Following graphs show how speed and energy of the pulse depends on the material thickness. There are optimal speeds from the experiment in the bond of the predicted value.



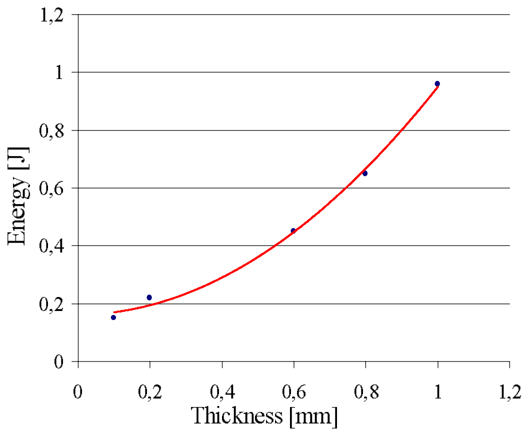


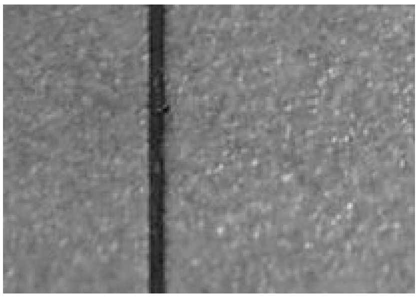
Fig. 3: Speed dependence of material thickness
Fig. 4: Energy dependence of material thickness.

The measuring of cut widths and their visual evaluation was made by means of a microscope NEOPHOT 2. There are values of cut widths in the table no.4. In the most cases the width decreases as speed increases.

| **h (mm)** | **v1** | **v2** | **v3** | **V4** | **v5** | **v6** | **v7** | **v8** |
|---|---|---|---|---|---|---|---|---|
| | **Cut width  for speeds v1 to v8 (mm)** | | | | | | | |
| 0,1 | 0,24 | 0,23 | 0,23 | 0,22 | 0,18 | 0,16 | 0,16 | 0,16 |
| 0,2 | 0,23 | 0,22 | 0,21 | 0,20 | 0,18 | 0,17 | 0,16 | 0,16 |
| 0,6 | 0,27 | 0,23 | 0,23 | 0,22 | 0,21 | 0,23 | 0,25 | * |
| 0,8 | 0,27 | 0,27 | 0,26 | 0,25 | 0,27 | 0,26 | * | * |
| 1,0 | 0,21 | 0,20 | 0,19 | 0,18 | 0,18 | * | * | * |

Table 4: Measured cut widths

In case of too high speeds a knurling appears along the cut, overlapping of pulses was insufficient. In case both of too slow and both of too high speeds black scales protrude above bottom surface of material. Comparing of the good and bad cut bottom side is showed on fig.5, 6 and 7.



F ig.5: Steel 0,6 mm, v = 3 mm/s

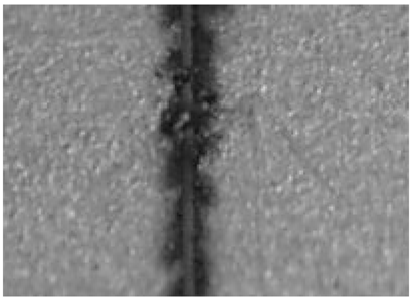


Fig.6: Steel 0,6 mm, v = 8 mm/s

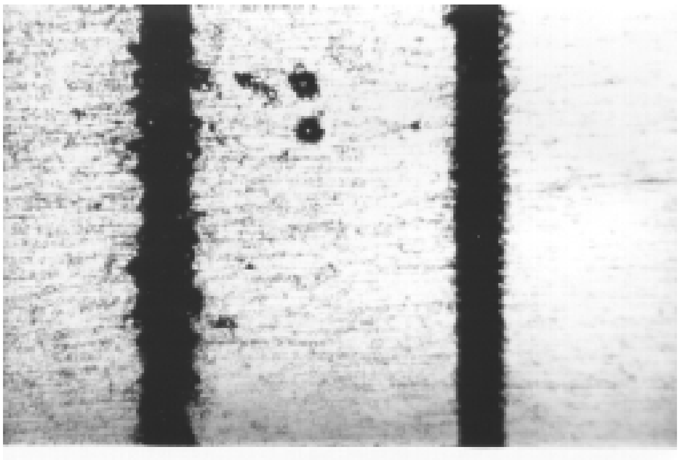


Fig.7: Steel 0,2mm, $v_{min}$ =  4 mm/s and  $v_{max}$ = 19 mm/s

# 4. CONCLUSION

The predicted parameters of the laser cutting of the steel were tested in experiment on Nd:YAG laser system with the average power 45W and focusing lens 100mm. Maximal value of thickness for cutting resonator was found 1mm. The optimal cutting of speed depends directly on average power and energy, inverse dependent on the material thickness. Physical material properties have also an important effect. Our experiments will continue with other metal materials, aluminium, brass or cooper and non-metals, wood, ceramic or glass.

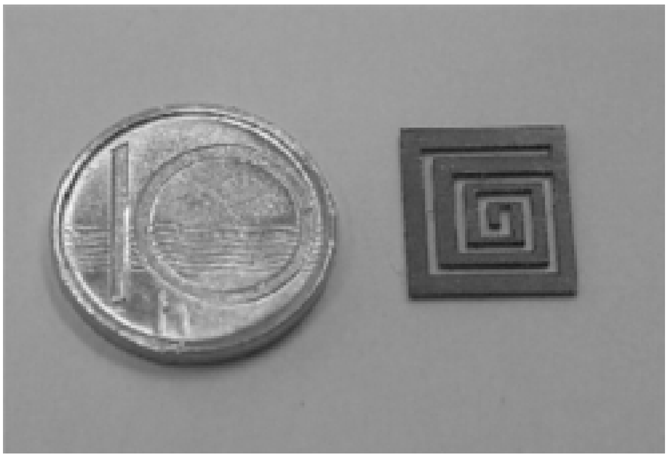


Fig.8: Cut shape from steel 0,1mm, special fine cutting resonator

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