ALT 12
Advanced Laser Technologies
2 – 6 September 2012, Thun, Switzerland

ALT 12
c/o Bern University of Applied Sciences
Engineering and Information Technology

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# PYROMETRIC MONITORING OF GAS-ASSISTED CUTTING OF STEEL USING FIBER LASER

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DOI: 10.12684/alt.1.47

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# Pyrometric Monitoring of Gas-Assisted Cutting of Steel Using Fiber Laser

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## Abstract

Measurements of the temperature in zone of action of laser radiation on the molten metal have been performed. The results are reported for different speed of cutting of mild-steel plate of 3 mm-thick with high-power fiber laser; oxygen was used as an assisted gas. Researches demonstrate that fluctuations of local temperature are related to unequal radiation absorption that associates with local deformations of surface of melt. Thus noise spectrum of those fluctuations reflects turbulent surface deformation caused by gas jet and capillary waves. The standard temperature deviation does not exceed 10 K on the frequency of 7 KHz and above, and power law of spectrum of density of fluctuations of local temperature is about “-2.8” in range of capillary turbulence. Thus we can distinguish radiation pulsation due to laser cutting from other processes of radiation affection to the sample, including unwanted, degrading the quality of technological operations. The results of investigation can be useful for monitoring laser cutting process.

## Introduction

Sheet-metal laser cutting is the largest, in terms of market of machinery, widespread industrial laser application. An investigation of the dynamics of the laser radiation action on the material and a development of the monitoring systems is one of the directions of quality improvement in laser-thermal technology. It can be mentioned a few papers published recently aimed to improve the performance of the cutting [1-5], all of them related to thermal technology using $CO_2$ laser. We investigated local thermal luminosity of melt in process of fiber-laser cutting of metal sheet using multichannel pyrometer, as described in [6]. The cutting with fiber laser is competitively solution since nearly 2006 [7], but researches on the characteristics of fiber-laser applications are still few in number.

## Experimental setup and results

A series of experimental cutting of a low-carbon steel sheet of 3 mm thick was made using Ytterbium-doped fiber laser YLS-3000 [IPG Photonics] with oxygen as an assist gas. The cutting speed was varied from 30 to 60 mm/s in experiments on cutting different specimens; the recommended speed of cutting metal plate of 3 mm thick was 40 mm/s for laser power of 1800 Watts. The pressure of oxygen was (0.3…0.5) MPa. The local brightness temperature was measure from the different depths on the cutting front (0.6 mm, 1.2 mm, 1.8 mm and 2.4 mm).

A luminosity of local area, about ∅100 μm, on the cut zone heated by laser radiation is collected by an optical lens and illuminates the end face of optical fiber located at an angle of ~30° to the plane of the sheet. The light delivered by each of four optical fibers to the own photo-sensor. The arrays of photo-sensors K1713-05 [Hamamatsu] are used. This type of detector incorporates an infrared transmitting Si photodiode mounted over an InGaAs p-i-n photodiode along the same optical axis. Thus the measurement of brightness temperature applied the two-color method of pyrometry: the local brightness temperature defined in this case as a function of ratio of photocurrents of two photodiodes sensitive to neighboring regions of the near infrared radiation spectrum. We used rejected filter to reduce the penetration of laser radiation to optical path of pyrometer. The scheme of experimental set-up is on fig.1 and the photo of laser head with pyrometer is shown on fig.2.

Figure 1 Experimental set-up (scheme)

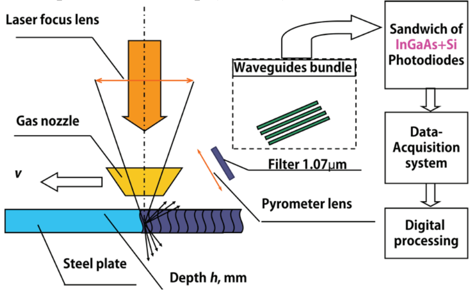
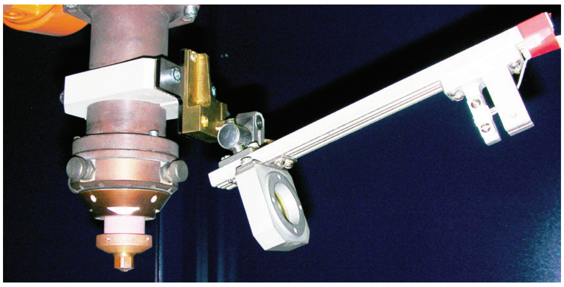


Figure 2 Experimental set-up (photo)



Some results are shown on fig.3-4.

Figure 3 Temporal dynamics of temperature on depth of 1.2 mm (bottom line); 1.8 mm; 2.4 mm (upper line) with cutting velocity 50 mm/s and pressure of oxygen is 4 bar.

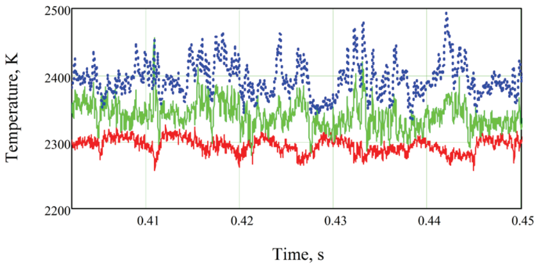
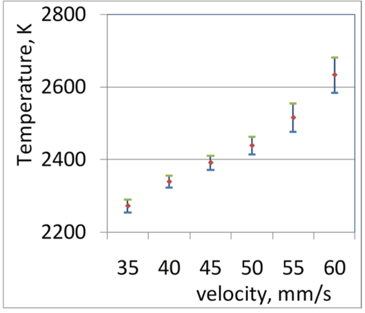


Figure 4 The dependence of the average temperature at 2.4 mm on cutting velocity in the same conditions.



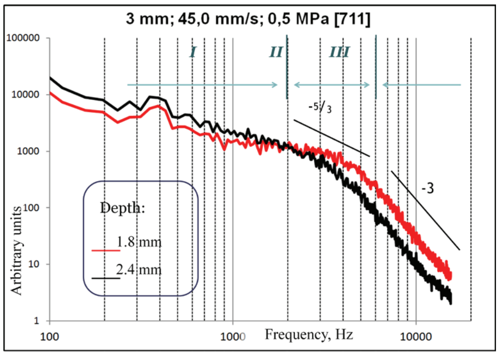
## Results and discussion

The results of measurements of the temperature fluctuations allow to calculate noise spectra of the temperature pulsations for the above - mentioned condition. The measurements were obtained by multichannel pyrometer on the various depths that allows us to trace spectra transformation along the front of cutting along front of cutting.

### *The noise-like spectrum of temperature fluctuations*

Averaging of power of spectra makes it possible to enhance the relative amplitude of resonance oscillations against the background of random oscillations. Some of that low-frequency resonance coupled with the roughness and longitudinal strips [8], but high-frequency resonances are additive interferences that must be born in mind when analyzing the spectra.

Figure 5 The noise spectra of temperature fluctuations

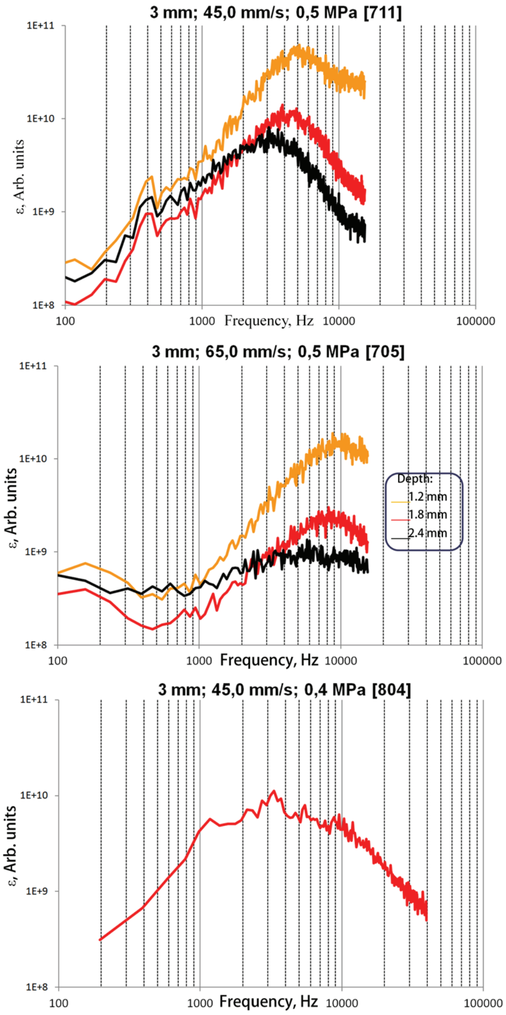


Standard deviation $\sqrt{E_T(\omega)}$ corresponding to variance spectrum of temperature is calculated as base to further investigations of physical factors affecting temperature variations in the zone of gas-assisted laser cutting of metals: spectra of pulsations of the local brightness temperature were obtained to define ranges of influence of different melt surface deformation mechanism and to define the parameters of capillary waves distribution (fig.5).

### *The spectrum of density of turbulent-energy dissipation*

The function $\varepsilon = E_T(\omega)\cdot\omega^2$, having the meaning density of turbulent energy dissipation [9], was calculated (fig.6). This function has the maximum in hydrodynamic turbulence on the boundary between inertial and viscosity domains and tends to zero in the high-frequency area. The measurements show the existence of conditions for developed turbulent flow in range (1…7) kHz.

Figure 6 The spectra of density of turbulent energy dissipation

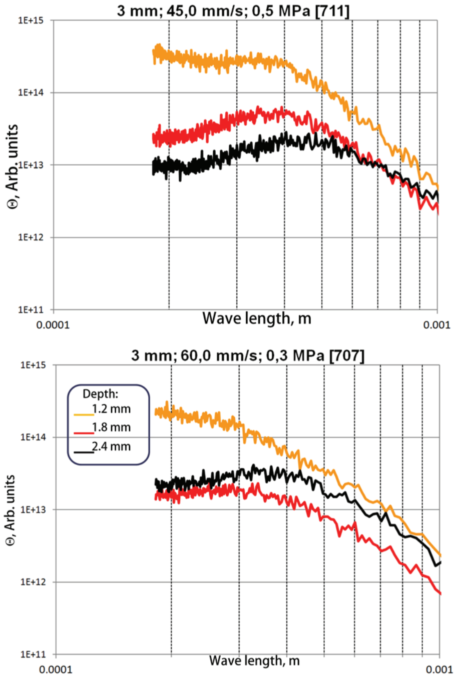


The maximum of ε is different for cutting conditions: its value rises with increasing oxygen pressure in described range of parameters. The frequency of maximum ε is increased with increasing of cutting velocity. The maximum of ε is localized near depth of (1.2…1.5) mm along the cutting front.

### *The phenomenon of capillary–wave turbulence*

Consider another auxiliary function $\Theta(k) = E_T(k)\cdot k^{9/2}$, where k is wave number, and dispersion $k^3 = \omega^2(\rho/\sigma)$ (ρ is melt density, σ is melt surface tension). Function Θ is near to constant in case of capillary–wave turbulence with low frequency energy input [10]. Capillary waves we obtained are intensified with cutting velocity increasing (fig.6). The range of capillary-wave turbulence expands along the cutting front. The function Θ is near to constant for capillary-waves shorter than 0.45 mm. The maximum of energy of short capillary-waves is on depth of (1.2…1.5) mm.

Figure 7 The spectra auxiliary function Θ



## Conclusion

These researches demonstrate that we can estimate the mechanism and regime of laser cutting by measuring the spectrum of heat emission pulsations. It is shown, that local fluctuations of T are related to local melt's surface deformations due to unequal radiation absorption. Thus noise spectrum of T fluctuations reflects turbulent surface deformation, caused by gas jet and capillary waves. Furthermore, the paper focuses on investigation of high frequency part of pulsation spectra, what is important to reduce the response time of emerging reaction on deviation from the given regime of laser cutting [11]. So the results of investigation can be useful for development of monitoring and quality control system of laser cutting process.

## Acknowledgement

The authors wish to thank the Russian Foundation for Basic Research for financial support (grant N 11-08-01094-a).

## References

[1] I. Decker, H. Heyn, D. Martinen, H. Wohlfahrt (1997), Process monitoring in laser beam cutting on its way to industrial application, in Proc. SPIE, 3097, pp.29-37

[2] J. R. Duflou, E. Fallahi Sichani, J. De Keuster, J.-P. Kruth (2009), Development of a Real Time Monitoring and Adaptive Control System for Laser Flame Cutting, In: 28th International congress on Aplications of Lasers & Electro-Optics (ICALEO 2009), November 2-5, 2009 - Orlando, FL, LIA Publication N 102. , Paper #1203

[4] V.S. Golubev, A.V. Dubrov, Yu.N. Zavalov et al. (2010), Diagnostics of laser radiance penetration into material by multi-channel pyrometer, In: International Conference on Advanced Optoelectronics and Lasers (CAOL), 10-14 Sept. 2010, Sevastopol (Ukraine), pp. 182 - 184 DOI: 10.1109/CAOL.2010.5634219

[5] W. Huang, R. Kovacevic (2012), Development of a real-time laser-based machine vision system to monitor and control welding processes, The Int-l J. of Advanced Manufacturing Technology, V.63, pp 235-248

[6] A. V. Dubrov, V. D. Dubrov, Y. N. Zavalov et al (2011), Application of optical pyrometry for on-line monitoring in laser-cutting technologies, Applied Physics B: Lasers and Optics, 105, pp. 537-543

[7] A. Kratky, D. Schuöcker, G. Liedl (2009), Processing with kW fibre lasers: advantages and limits, in Proc.SPIE, 7131, 71311X

[8] V. S. Golubev, R. V. Grishaev, V. D. Dubrov, et al. (2008), On-line diagnostic in technology of the gas - jet assisted laser fusion cutting, In: Proceed. of XIId Int.Conf. on Phys. and Chem. processes in selection of atoms and molecula, March 31-Apr 4, 2008, Zvenigorod, Russia, TsNIIAtomInform: Moscow, , pp. 255-260 [-in Russian]; ISBN 978-5-89513-133-6

[9] L. D. Landau, Ye. M. Lifshitz, [Theoretical physics (10 vol.), Hydrodynamics], vol.VI, Nauka, Moscow (1986)

[10] L. V. Abdurakhimov, M. Yu. Brazhnikov, A. A. Levchenko, L. P. Mezhov-Deglin (2008), Developed Capillary Turbulence on the Surface of Normal and Superfluid 4He, J. of Low Temperature Physics, 150, pp. 426-430

[11] F. Kh. Mirzoev, V. Ya. Panchenko, L. A. Shelepin (1996), Laser control processes in solids, Phys. Usp., 39, pp. 1–29