



Investigation of the Influence of Power Density and Frequency on Laser Drilling in Metal Samples

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Abstract: To study the influence of the main parameters on the process of laser drilling in various samples from aluminium, copper and silver, numerical experiments are carried out with specialized software TEMPERATURFEL3D, working in MATLAB. The results refer to the fiber laser and CuBr laser - modern laser, whose applications in various technological processes are still being explored. The dependences of the depth of the hole on the power density and the frequency are obtained. The influence of power density is analyzed. Operating range for the frequency for the considered process is determined.

Keywords: numerical experiments, software, laser drilling, fiber laser, CuBr laser.

I. Introduction

Lasers are widely used in many areas – not only in laser processing of materials, in processing of thin films and microstructures, in measuring equipment, in urban engineering, in medicine, in the military industry, in agriculture, in holography but also for transporting information and processing it optically, for obtaining plasma, for laser emission spectral analysis, and for many other purposes in science and education. Laser technology is used in the processing of materials with huge success. This includes technological processes in metals and alloys [1]-[3] such as marking and engraving, cutting, welding, drilling, scribing. For lasers' widespread use for practical purposes contribute the specific properties of the laser radiation - high coherence monochromaticity, high directionality, ability to achieve high energy density (and power density, respectively) in the treated area. Laser sources emit radiation with wavelengths in a wide range of the spectrum - from ultraviolet, through visible and to infrared in both continuous and pulsed modes. Furthermore, in recent years new lasers were constructed with the appropriate characteristics and properties to provide the required technological parameters for treatment of the materials.

II. Presentation

The purpose of the study is to investigate the influence of the power density and to determine of the operating range for the frequency for drilling holes in samples of aluminum, copper and silver via fiber laser and CuBr laser. A large number of numerical experiments are conducted with the software TEMPERATURFEL3D [4], working in MATLAB. It provides the following options for the output results:

- Animation of the whole process;
- Temperature profile of the sample in a given time;
- profile of the maximum temperature;
- temperature's dependence on time;
- temperature changes of the sample in the depth.

The realization process of laser drilling depends on the thermo-physical and optical properties of the material [5]-[6]. This requires conducting experiments in the specific metals. Table I shows some basic characteristics of the studied materials [7]-[8].

Table I. Some thermophysical parameters of the metals aluminium, copper and silver

Metal	Al	Cu	Ag
Magnitude			
Thermal conductivity k , W/(m.K)	236	401	429
Specific heat capacity c , J/(kg.K)	830	380	232
Density ρ , kg/m ³	2700	8920	10490
Diffusion coefficient a , m ² /s	$1,05 \cdot 10^{-4}$	$1,18 \cdot 10^{-4}$	$1,76 \cdot 10^{-4}$
Temperature of melting T_m , K	933,5	1357,6	1235
Temperature of evaporation T_v , K	2972	2830	2435

Numerical calculations have been made in two directions:

- Investigation of the influence of power density.
- Determining the operating range for the frequency.

The main parameters of the lasers and the technological systems to which the numerical experiments are applied are given in Table II [9]-[10].

Table III. Some basic parameters of the used lasers and technological systems

Parameter	Laser	Fiber laser	CuBr laser
Wavelength λ , nm		1064	511
Power P , W		100	50
Frequency ν , kHz		50	20
Quality of beam M^2		1,1	1,3

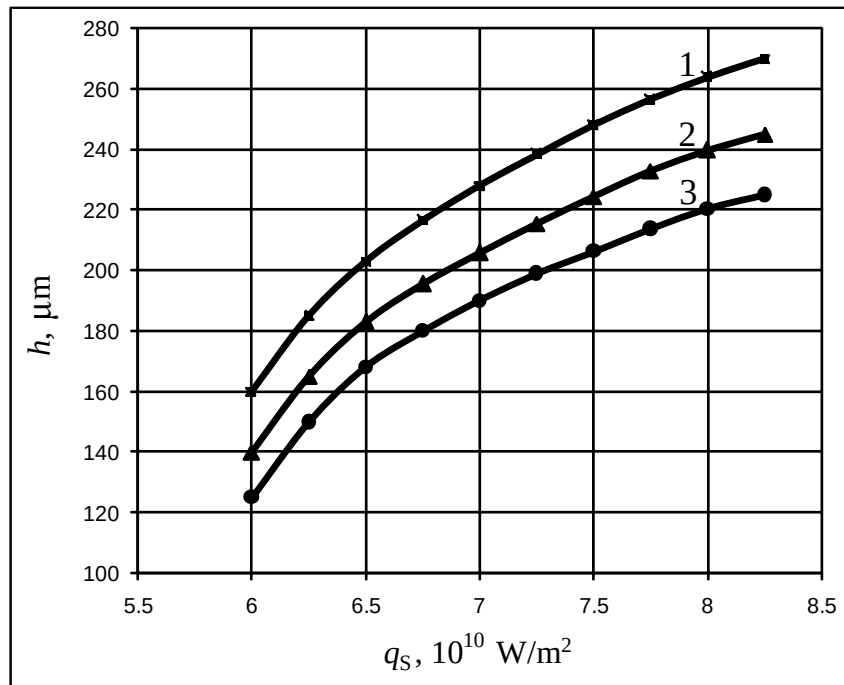
III. Results of numerical experiments

A. Investigation of the influence of power density

Large number of numerical experiments are conducted and analyzed. Through the computations the power density is changed in the intervals $q_s \in [6,00 \cdot 10^{10}; 8,25 \cdot 10^{10}] \text{ W/m}^2$ with a step of $0,25 \cdot 10^{10} \text{ W/m}^2$ for fiber laser and $q_s \in [4,00 \cdot 10^{10}; 6,25 \cdot 10^{10}] \text{ W/m}^2$ with a step of $0,25 \cdot 10^{10} \text{ W/m}^2$ for CuBr laser. The treatment time is kept constant and the frequency is $\nu = 20 \text{ kHz}$ for both of the lasers.

Fig. 1 and fig. 2 show the dependence of the depth of the hole h on the power density q_s for the fiber laser and the CuBr laser, respectively. From them, the following conclusions are reached:

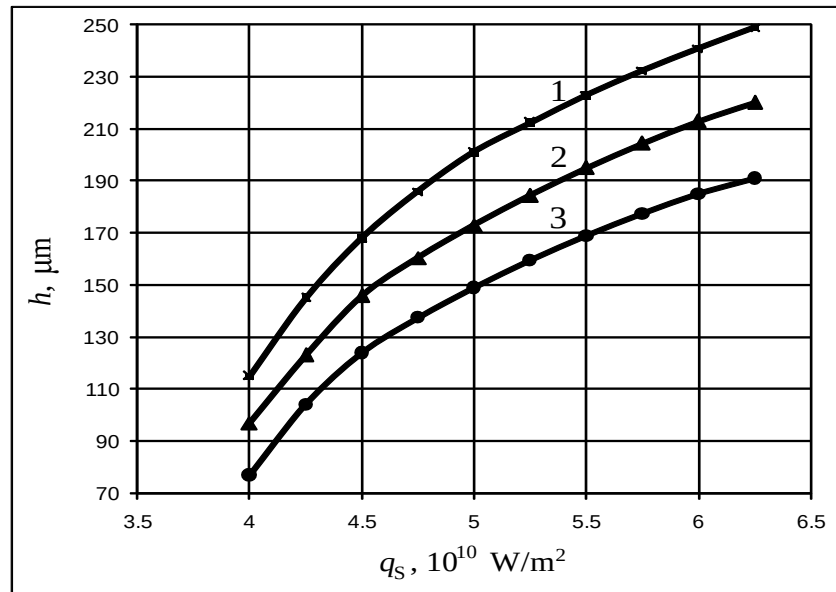
Figure 1: Dependence of the depth of the hole h on the power density q_s for the fiber laser for: 1) Al; 2) Ag; 3) Cu



- As the power density increases a nonlinear increase in the depth of the hole for both lasers is observed;
- The speed of growth of the depth of the hole in the interval $q_s \in [6,50 \cdot 10^{10}; 8,25 \cdot 10^{10}] \text{ W/m}^2$ for fiber laser is:
 - $3,83 \cdot 10^{-9} \mu\text{m}/(\text{W/m}^2)$ in Al;
 - $3,54 \cdot 10^{-9} \mu\text{m}/(\text{W/m}^2)$ in Ag;
 - $3,26 \cdot 10^{-9} \mu\text{m}/(\text{W/m}^2)$ in Cu.
- The speed of growth of the depth of the hole in the interval $q_s \in [4,50 \cdot 10^{10}; 6,25 \cdot 10^{10}] \text{ W/m}^2$ for CuBr laser is:

- $4,63 \cdot 10^{-9} \mu\text{m}/(\text{W}/\text{m}^2)$ in Al;
- $4,23 \cdot 10^{-9} \mu\text{m}/(\text{W}/\text{m}^2)$ in Ag;
- $3,83 \cdot 10^{-9} \mu\text{m}/(\text{W}/\text{m}^2)$ in Cu.

Figure 2: Dependence of the depth of the hole h from the power density q_s for the CuBr laser for: 1) Al; 2) Ag; 3) Cu



- In order to achieve a certain depth of the hole using a fiber laser 25% more power density is required than that for the CuBr laser. This is caused by the different absorption rates of the laser radiation for the two wavelengths.

B. Determining the operating range for the frequency

During the numerical experiments the frequency is changed in the interval $\nu \in [6, 20]$ kHz with a step of 2 kHz for the CuBr laser and $\nu \in [10, 50]$ kHz with a step of 5 kHz for the fiber laser. The influence time is kept constant and the power density is $q_{s1} = 7,50 \cdot 10^{10} \text{ W}/\text{m}^2$ for the fiber laser and $q_{s2} = 5,25 \cdot 10^{10} \text{ W}/\text{m}^2$ for the CuBr laser.

Figure 3. Dependence of the depth of the hole h on the frequency ν for the fiber laser for: 1) Al; 2) Ag; 3) Cu

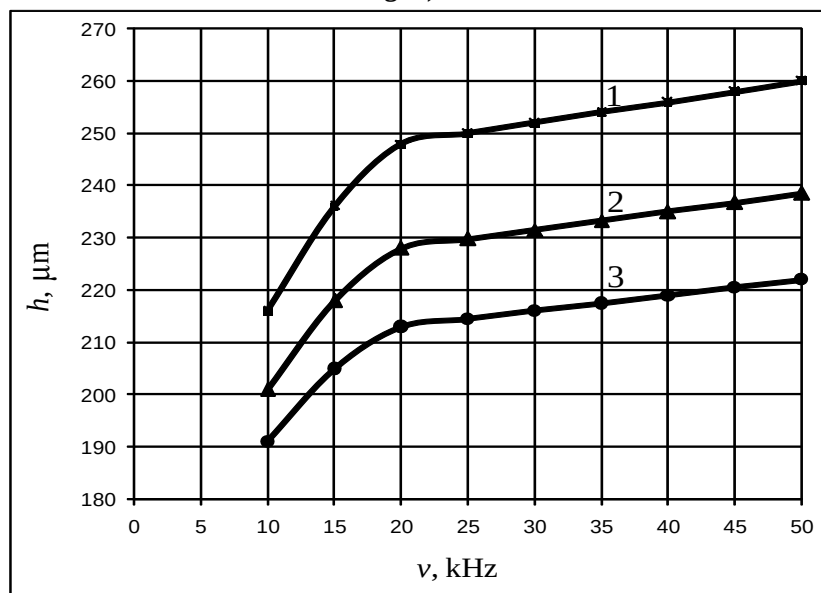


Figure 4. Dependence of the depth of the hole h on the frequency ν for the CuBr laser for: 1) Al; 2) Ag; 3) Cu

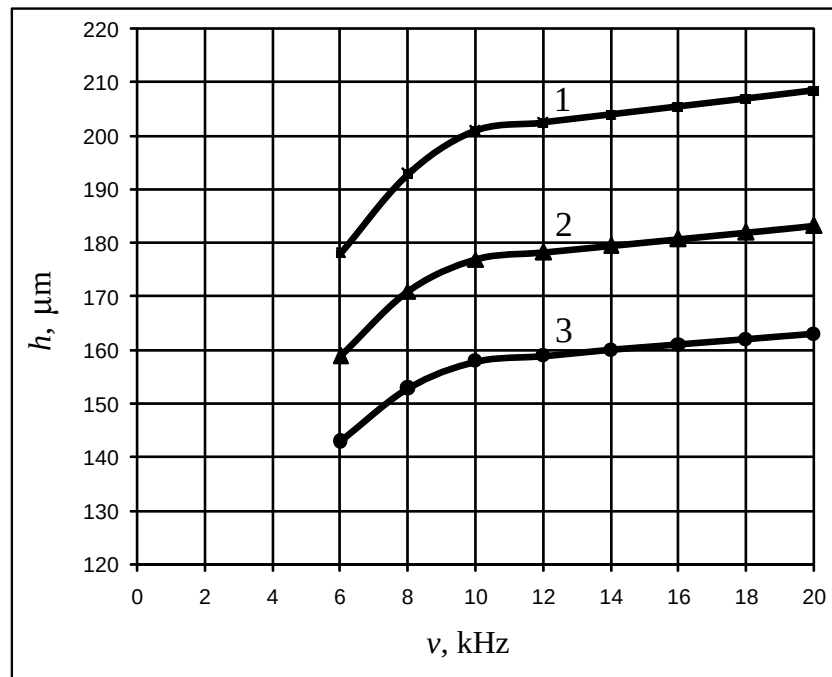


Fig. 3 and fig. 4 show the dependence of the depth of the hole h on the frequencies for the fiber laser and the CuBr laser, respectively. From them, the following conclusions are reached:

- As the frequency increases a nonlinear increase in the depth of the hole in the intervals $\nu \in [10, 20]$ kHz for the fiber laser and $\nu \in [6, 10]$ kHz for the CuBr laser is observed. In the intervals $\nu \in [20, 50]$ kHz for the fiber laser and $\nu \in [10, 20]$ kHz for the CuBr laser there is a very slow linear increase in the depth of hole;
- The speed of growth of the depth of the hole in the interval $\nu \in [20, 50]$ kHz for the fiber laser is:
 - 0,40 $\mu\text{m}/\text{kHz}$ in Al;
 - 0,35 $\mu\text{m}/\text{kHz}$ in Ag;
 - 0,30 $\mu\text{m}/\text{kHz}$ in Cu.
- The speed of growth of the depth of the hole in the interval $\nu \in [10, 20]$ kHz for the CuBr laser is:
 - 0,75 $\mu\text{m}/\text{kHz}$ in Al;
 - 0,62 $\mu\text{m}/\text{kHz}$ in Ag;
 - 0,50 $\mu\text{m}/\text{kHz}$ in Cu.
- The operating ranges for the frequency are:
 - $\nu \in [20, 50]$ kHz for the fiber laser;
 - $\nu \in [10, 20]$ kHz for the CuBr laser.

III. Conclusion

The obtaining of operating ranges for the frequency are required for the conducting real experiments and the creating of technological tables with the optimal parameters for laser drilling. The latter are to assist the operator of the technological laser system. Usage of technological tables leads to shorter time to deployment of the technology in the production process, when the product's material is changed.

IV. References

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