

3D Graphic Images of Laser Induced Temperature Fields

Lyubomir Lazov¹ and Nikolaj Angelov²

Abstract – A possible to obtain three-dimensional graphic images of laser-induced temperature fields at different moments of time for samples of tool steel is shown. Optimal intervals for certain parameters when using Nd: YAG-laser are determined.

Keywords – graphic images, laser, temperature field

I. INTRODUCTION

Theoretical model investigations in the field of laser radiation interaction with the substance are of key importance to the analysis of experimental results obtained during various technology processes [1]. Similarly, this appears to be a principal factor which determines the trends in conducting a number of novel experimental investigations. In summary their role in the specific practical applications of lasers in treating materials can be rendered in the following way:

- Determining of destruction threshold in treating certain type of material by laser source;
- Optimizing the course of various laser technology processes such as marking, etching, cutting, welding, boring of holes, hardening etc.;

II. PRESENTATION

With laser impact on tool steel a portion of the radiation is absorbed whereas the remainder part is reflected by the surface and another third part passes through it thus satisfying the condition

$$E = E_A + E_R,$$

Where E is the energy of falling radiation, E_A - is the energy of absorbed radiation, E_R - is the energy of reflected radiation.

In fig. 1 is shown a general diagram of energy distribution of the process of laser impact upon alloys and metals (including tool steel).

Apart from the energy gained through absorbed radiation it is possible to obtain in the impact zone some energy which is produced by way of chemical reactions E_{ch} while its temperature change. The energy balance equation is then

$$E_A + E_{ch} = E_{proc} + E_c + E_r + E_{con} \quad (1)$$

where E_{proc} is the energy of the process; E_c - is the energy which has entered the thermally impacted zone around

the work space; E_r - is the energy of radiation; E_{con} - is the energy loss due to convection.

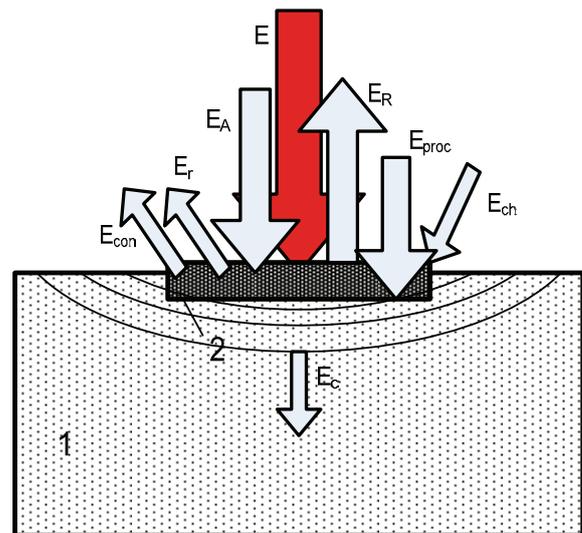


Fig.1 a general diagram of energy distribution of the process of laser impact upon alloys and metals

Physical model

In the theoretical model under observation the calculations for the laser induced temperature fields are made by taking into account these restrictions:

- Ignoring thermal losses resulting from convection and radiation;
- Ignoring non-uniformities and non-homogeneities in the impact zone.

Likewise, the thermal impact of laser radiation in the treatment zone in the model is assigned by the heat conduction equation of the kind

$$c\rho \frac{\partial T}{\partial t} = \text{div}(k \text{ grad } T) + q_s(1 - R)\alpha, \quad (2)$$

where T is temperature; t - time; c - specific thermal capacity; ρ - density; k - coefficient of thermal conductivity; q_s - laser radiation power density; R - coefficient of reflection; α - coefficient of absorption.

Since the absorption of the falling laser radiation takes place in a thin layer close to the surface [] in the theoretical model it is possible to regard thermal impact as surface heat source. In laser marking of metal surfaces with pulse durations being in the range $\tau = (10 - 1000)$ ns this requirement is in effect because the thickness of the sample

¹Lyubomir Lazov is with the Technical University of Gabrovo, Hadzhi Dimitar 4, 5300 Gabrovo, Bulgaria, E-mail: lazov@tugab.bg

²Nikolaj Angelov is with the Technical Sciences of Gabrovo, Hadzhi Dimitar 4, 5300 Gabrovo, Bulgaria, E-mail: bo232001@yahoo.com

under marking is much greater than the depth of penetration δ of laser radiation ($\delta = 1/\alpha$).

By means of the theoretical model it is possible to estimate the required power density at which the surface material is being melted. The latter is of great importance for the method of laser marking effected by way of structural changes of second order or by oxidization.

Laser marking by means of taking off a pre-marked layer on the sample enjoys a considerable amount of practical application [2]. The theoretical model allows to perform calculations in various solutions such as:

- Laser radiation is allowed through the layer and absorption takes place at the layer/pad boundary;
- Laser radiation is absorbed by the layer, then evaporates it thus uncovering the base material.

An important aspect in laser marking is the calculation of laser induced temperature fields in treatments utilizing phase changes in the material. The proposed theoretical model allows the solution of this task as well. Heat conduction equations in this case are to be solved for both solid phase and the molten metal.

In terms of practical application it is interesting to make observation of the case in which the material underneath the surface in the absorption zone starts boiling and bursts out due to the generated high pressure; part of that material is deposited aside of the marking zone in the form of splashes. During work with pulses of $\tau = 10$ ns sublimation (direct evaporation from the impact zone) is observed. This process is of great importance in the case of precision etching of metal surfaces.

Theoretical model estimations could be subjected to the following principal tasks which are of substantial importance to the specific processes and methods of laser marking and etching:

- Clarifying the effect of the wave length λ of laser radiation for the concrete material. This facilitates the selection of appropriate laser source (fiber laser $\lambda = 1064$ nm, Nd:YAG laser with $\lambda = 1064$ nm, laser of CuBr with $\lambda = 511$; 578 nm, eximer lasers (in the ultra-violet range) etc.;
- Clarifying the role of the duration of pulses τ in spatial distribution of temperature field and the physical process of radiation interaction with the metal $\tau = (10 - 1000)$ ns;
- Determining the effect of diameter d at the work spot upon temperature distribution $d = (10 - 200)$ μ m;
- Clarifying the role of pulses frequency upon the temperature field;
- Clarifying the role of the laser beam relative speed of displacement, with regard to the treated surface, upon the profile of the temperature field;

Basic elements of related software

Temperaturfeld3D software is the working medium for calculating temperature fields with a wide set of input parameters and possibilities for analysis of estimated results [3].

Two models of estimation are used: dynamic and static. In the dynamic model the laser beam moves within xy-co-

ordinate system and affects the material. Temperature fields are determined both at the surface of material and in depth. In this case there are 3 dimensions x , y and z , which determines the complexity and time for calculations. In static model laser beam remains static and the material has radial symmetry. In Thus dimensions are reduced to $2 - r$ and z and calculation is accelerated considerably.

After selecting a model the main window drops. From there the user has access to the three principal sections of software- input/output; model parameters and calculation.

To calculate one of the models it is necessary to enter a lot of parameters:

Program/Software parameters

- File name
- Initial time step/interval
- Minimum time step/interval
- Maximum time step/interval
- End up of calculations
- Ambient temperature
- Radiative capacity
- Calculations accuracy
- Initial time for storing results
- Coefficient of storing
- Liquid phase transition
- Method for model calculation

There are two methods available: Gear and Adams with a variety of sub-versions.

Geometry parameters

Here are defined geometry dimensions of treated sample as well as the number of composite materials it is made of.

- Geometry model

Three geometry models are available: rectangular prism, layer, semi-space.

- Computerized generation of elements
- Geometry dimensions

Laser parameters

Laser radiation and movement are assigned here.

- Type of laser
- Time distribution of power density
- Gaussian radius of beam
- Time for following of pulses
- Initial co-ordinates and laser beam speed

Materials parameters

The relationship between the number of various materials indicated by the geometry parameters and the parameters of materials themselves is made in here

- List of available materials
- Booting data base
- Defining a new material

In a series of windows wherein the four groups of parameters are defined: reflection coefficient; heat conduction coefficient; specific heat capacity; absorption capacity.

- Change of parameters of certain material

Calculation

The stages of calculation are described in the items that follow:

- Preparation

Prior to starting calculations all necessary parameters are checked for availability.

- Calculation and results

Following the writing of data in the respective file, the calculation kernel is activated to perform calculation of temperature fields.

- Calculations analysis

Upon opening analysis window all data from the file with calculated results are booted automatically:

- approximation of results;
- animation of the entire process;
- temperature profile of material at certain moment;
- maximum temperature profile
- temperature time dependence;
- material in-depth change of temperature ;

Examples of numeric experiments

By means of this product(software) numeric calculations are done aiming at finding out appropriate operation mode for marking samples made of tool steel type Y11 with Nd:YAG laser by way of the surface structural changes method. The aim is to determine the distribution of laser radiation absorbed energy inside the sample according to the developed physical model [4] and to compare the results with the experimental investigations. Marking done by this method is carried out below the surface destruction threshold for steel type Y11 that is ,the temperature in the treatment zone in numeric experiments should not exceed melting temperature (1820 K). In numeric experiments the zone under laser impact is divided into three layers with thickness of $\Delta h_1 = 12,5 \mu\text{m}$, $\Delta h_2 = 30,0 \mu\text{m}$, and $\Delta h_3 = 300 \mu\text{m}$. The time for laser impact is kept constant i.e the speed of movement, duration and frequency of pulses in numerical experiments remain unchanged.

In fig. 2 and fig 3 and fig. 4 are shown temperature profiles for different layers of the sample for time moment $t = 3 \text{ ms}$ following the start up of the process. The movement of the laser beam is along the Oy axis and the process starts from a point with co-ordinates (2mm,0). The parameters of the laser radiation and the technology process are:

Wave length	$\lambda = 1064 \text{ nm};$
Power density	$q_s = 5,70 \cdot 10^9 \text{ W/m}^2;$
Duration of pulses	$\tau = 100 \text{ ns};$
frequency	$\nu = 10 \text{ kHz}$
velocity of marking	$v = 20\text{m/s}..$

The graph in fig 2 concerns the first layer of the tested sample; fig 3 concerns the second layer and fig 4 concerns the third layer. Temperature drop in depth is in accordance with the physical model which describes laser radiation absorption by the free electrons in metals and alloys. The depth of penetration of the of laser radiation is $\sim 10^{-7} \text{ m}$, which suggests the consideration of surface heat source.Heat is distributed across material by way of heat conduction (1). For the short time interval of laser impact ($\sim \text{ms}$), depending on the rate of marking and cooling of the impact zone, ($\sim 10^{-6} \text{ K/s}$) heat cannot reach a substantial depth . From the graph in fig. 4 it is evident that in depth the maximum temperature is equal to 450 K.

Numerical experiments lead to the conclusion that the depth of marking done by the method of structural changes

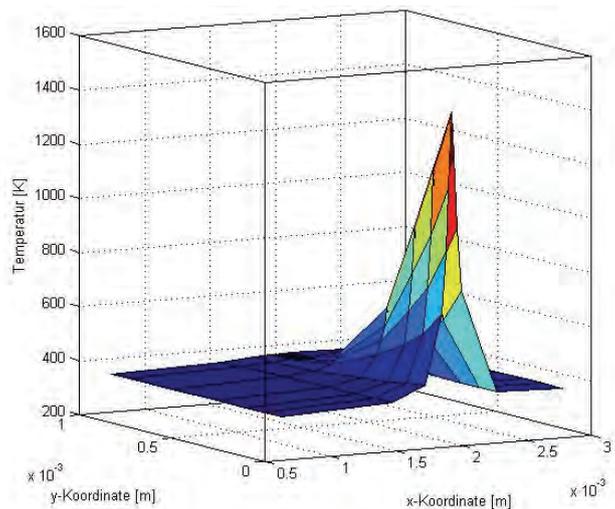


Fig.2 Temperature field of the upper layer with thickness of $\Delta h_1 = 12,5 \mu\text{m}$ for sample made of steel type Y11 impacted by Nd:YAG laser

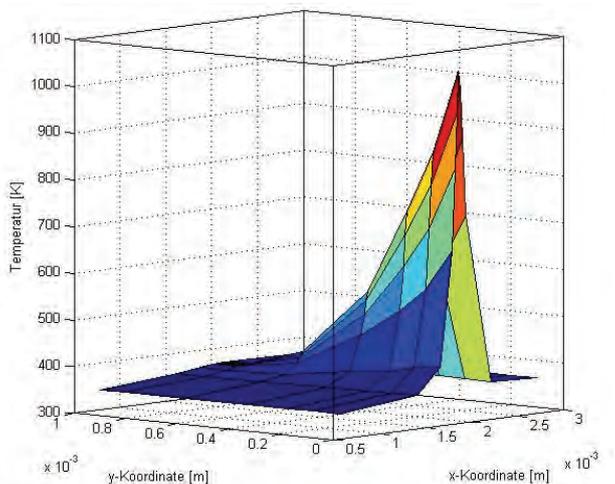


Fig.3 Temperature field of the upper layer with thickness of $\Delta h_2 = 30,0 \mu\text{m}$ for sample made of steel type Y11 and impacted by Nd:YAG laser

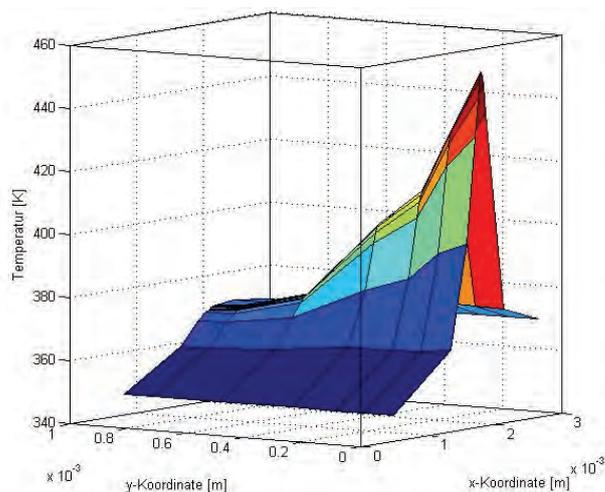


Fig.4 Temperature field of the upper layer with thickness of $\Delta h_3 = 300 \mu\text{m}$ for sample made of steel Y11 impacted by Nd:YAG laser

in the surface layer of the sample is approximately equal to 40 μm . It is a known fact that structural changes in steel take place within the temperature interval K. Results obtained from numerical experiments correlate well with those obtained by real experiments [5].

III. CONCLUSION

Numeric experiments for determining temperature fields by means of this product are appropriate not only for optimizing the process of laser marking but also for other laser technology processes such as cutting, welding, boring, hardening etc. Compared with the real experiment results they contribute to the rise in quality and effectiveness of laser treatment processes. The software features options for laser treatment numeric experimentation concerning various materials from mechanical engineering, electronics instrument engineering etc.

REFERENCES

- [1] Reinhart Poprawe Lasertechnik für die Fertigung, Springer 2004 ISBN 3-540-21406-2
- [2] Динев Н. Лазерите в модерните технологии, изд. Алфа, София, 1993
- [3] Белев И. Среда за пресмятане на лазерно индуцирани температурни полета, Дипломна работа, Технически университет, Габрово, 2009
- [4] Angelov N. Determining Temperature Fields under Laser Treatment of Solid Bodies with a Model of Semi-Bounded Body Having an Internal Heat Source, International scientific conference UNITECH'04, Gabrovo, Bulgaria, 18-19 November 2004
- [5] Lazov L., N. Angelov, A. Atanasov Optimization of the Parameters of the Laser Irradiation during the Marking on Instrumental Steel, International scientific conference UNITECH'04, Gabrovo, Bulgaria, 24-25 November 2006