Efficiency Increasing of Laser Technologies Application for Identification of Art and Industrial Products

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Abstract. The relation between properties of industrial products and individual characteristics of the laser technology production was researched. The analytical expressions for calculating of the depth of penetration of laser radiation into the material are derived in this paper; these expressions allow to increase the efficiency of laser technologies application, to choose optimal laser parameters, and to consider microstructure, chemical composition and mechanical properties of the material. The solution of topical problem of technological modes establishing is proposed, considering multiple versions of technology and laser equipment choices and considering indeterminacy of thermal properties of material. The complex index is distinguished, that index greatly simplifies selection of laser radiation parameters and allows to make atlas of materials thermal diffusivities.

Keywords: laser technology, engraving, material, thermal properties, art and industrial products, thermal diffusivity

INTRODUCTION

Nowadays laser marking and engraving are literally applied in all branches industry production, in instrument engineering, in identification and protection coding of the industrial models, in labeling of instrument panels, measuring tools, keyboard fields, in manufacturing of plates and signboards and in artistic decoration products. Development of scientific progress has increased necessity for esthetic improvement of all industrial production. Technique is one of the most important component of spiritual wealth, an organic part of the subjective world, and of the artificial environment of human life, its penetration is deeper and more extensive into all spheres of human life. That's why understanding of importance of harmonization of the richest and most complex world of subject forms and their relationship between each other come to the level of social objectives of the society, it's acquiring educational, ideological nature, increasing the importance of creating a comfortable in use, complete in form, esthetically perfect industrial products that meet both high technical and economic requirements, with a high degree of artistic expression.

The individual characteristics of each industrial product, independence of the author's intention, artistic taste, art of execution, disclosure of the artistic properties of the material like as its color richness, softness, and plastic are determining the dependence of the shape of the art and industrial products from its purpose, determining the relationship between function and design solution, between form and design, material, production technology [1].

Currently, the expansion of functional possibilities of the instrument and the complexity of forms of products are take place, the detailing of the terrain is increasing, the surface geometry is becoming more complex, the original color solutions are offering, so high artistic expression of the finished product is achieving. But hand-made production process is extremely time consuming and requires a considerable amount of time, that’s why the cost of hand-made products is high enough. Mechanical manual processing was replaced by automated one as a result of the development and improvement of high technologies. In its turn, the mechanical processing was replaced by the laser one [2]. Laser processing is more precise and has already became more cheap, it allows to make organic combination of design and industrial production.

Widespread in industrial production laser technologies [3] are rarely applied for identification imaging (bar codes, pictograms, numbers, etc.) to identifies the author, place and time of production, material composition, etc., due to additional requirements for esthetic properties, such as shape, pattern, texture and color, and the lack of proven methodologies. A number of theoretical and practical issues remain as insufficiently studied. In particular, the relationship between technological modes of laser equipment and surface characteristics of industrial products in the laser engraving is not studied. As usual, technological modes are establishing under the finished product experimentally. Current regulations ignore procedural issues that are related to the organization and the realization of an objective assessment of surface quality in engraving. Different definitions of terms create additional confusion and lead to the serious consequences, that are limiting wide application of laser technologies for wood processing.

The aim of this work is to study possibility of efficiency increasing of laser technologies application for identification imaging of artistic and industrial products of glass, ceramics, organic glass, plastic, metal and other materials by establishing of correlation and regression relationship between technological modes of laser equipment and surface characteristics of industrial products.

INFORMATION THEORY

There is a thermal separation process under the laser radiation to all kinds of materials, like the burning process. The thermal effect under the laser radiation is defined by the laser radiation parameters and thermal properties of material that depend from its microstructure [4].

As a result of thermal effect by the laser radiation, material begins to heat up. For example, there is only moisture remove by evaporation or boiling for organic materials at the temperature of 100...105 °C. When material is heated to the temperature of 105...150 °C, the drying process ends with the release of gaseous decomposition products. Material acquires a yellow and yellowish-brown color. The temperature increase in this stage occurs only due to action of external thermal energy source. At the temperature of 150...275 °C release of gases is intensifying and vapors of resinous substances are starting to release. Individual flares of gases are appeared at the temperature of 225...235 °C. Material is becoming darker, and its decomposition mainly proceeds only due to action of external thermal energy source. Decomposition of material with heat release (exothermic reaction) begins at the ignition temperature (about 275...290 °C), so a lot of flammable vapors and gases, gaseous products of pyrolysis are produced. If heating to such temperature does not occur, so material stops to burn after removal of the heat source. The described process is also suitable for industrial products of organic glass, cloth, leather, glass, ceramic, stone. The separation process is similarly at other temperatures.

Based on the above, using the expressions given in [5], in case of the laser beam has a Gaussian profile, and the absorbed laser radiant flux surface density is constant and equal to F_0, the temperature distribution in the solid material and its change in time is described by the expression:

$$T(r,z,t)=\frac{d^2\chi^{1/2}F_0}{K\pi^{1/2}}\int_0^t \frac{\exp\left(\frac{-z^2}{4\chi t}\right)\exp\left[\frac{-r^2}{4\chi t+d^2}\right]}{t^{1/2}\left(4\chi t+d^2\right)}dt, \tag{1}$$

where F_0 is the absorbed laser radiant flux surface density in the center of the spot of exposure, [W/m^2]; r is the distance from the center of the heated spot, [m]; z is the depth of heating that counted from the surface of material, [m]; T is the temperature, [K]; χ is the thermal diffusivity, [m^2/s]; K is the thermal conductivity, [W/(m·K)]; t is the time interval from start of exposure to laser radiation, [s]; d is the diameter of the laser spot on the surface of material, [m].

To determine the temperature in material under the fixed and the same distance from the center of the heated spot and the depth of heating, that counted from the surface, considering that calculation of the integral, which integrand includes the exponential function, use the integration by substitution, the expression (1) will be transformed to the following one:

$$T(t)=\frac{F_0 d}{K\pi^{1/2}}\cot\left(\frac{4\chi t}{d^2}\right)^{1/2}. \tag{2}$$

As a result of representation of trigonometric function cot(x) as a series and using of the first three terms of this series, that introduces an error less than 5 %, but greatly simplifies calculations, there is obtained:

$$T(t)=\frac{F_0 d}{K\pi^{1/2}}\left[\left(\frac{4\chi t}{d^2}\right)^{1/2}-\frac{\left(\frac{4\chi t}{d^2}\right)^{3/2}}{3}+\frac{\left(\frac{4\chi t}{d^2}\right)^{5/2}}{5}\right]. \tag{3}$$

After using of the ratio for describing the relationship between the main laser radiation parameters and material properties [6], the expression, that determine the depth of penetration of the radiation into material, is obtained:

$$h=\frac{4P}{C_p\rho T\pi d^2}, \tag{4}$$

where P is the power of radiation, [W]; C_P is the heat capacity of material, [J/K]; ρ is the density of material, [kg/m^3]; h is the depth of penetration of the radiation into material, [m]; d is the radius of the laser spot on the surface of material, [m]; $T(t)$ is the temperature change of the material during the heating, [K].

Considering that the thermal diffusivity of non-metallic materials is about 10^{-8} m^2/s, the expression (3) can be limited to the first term, after substituting (3) into the expression (4), there is obtained:

$$h = \frac{2PK}{C_p \rho F_0 d \pi^{1/2} \chi^{1/2} t^{1/2}} \quad (5)$$

denoting $\frac{2K}{C_p \rho F_0 d \pi^{1/2} t^{1/2}}$ as γ, the depth is given by:

$$h = \frac{\gamma P}{\chi^{1/2}}. \quad (6)$$

DESCRIPTION OF THE EXPERIMENT

Since the thermal properties of materials depend from temperature nonlinearly, the half-tone gray scale, (GOST 24930-81. Facsimile equipment gray scale. Technical requirements) was reproduced from white to black areas by the laser engraving machine of Speedy series of the Trotec company (Austria), with using of the CorelDraw and JobControl software, when the laser output power was being changed from 2 W to 12 W, the speed of movement of the laser beam was being changed from 10 cm/s to 180 cm/s, resolution was being changed from 100 dpi to 1000 dpi, pulse frequency was being changed from 500 Hz to 1000 Hz, the diameter of the focused laser beam on the material surface was being changed from 0.05 mm to 1.0 mm, the angle of incidence of the laser beam was being changed from 0 to 45 ° and these modes was being combinated, to check the correctness using of the expression (6) for the experimental determination of the depth of penetration of laser radiation into material. The experiments were being made by the reproduction of the halftone gray scale on wood of tangential, radial and end cut, on natural and artificial leather, and by the reproduction of the light and dark tones on bone, organic glass, Fig. 1.

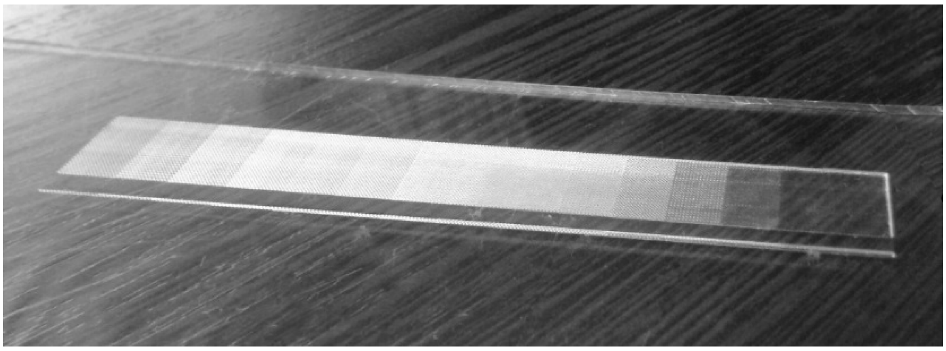

Figure 1. Reproduction of the halftone gray scale on organic glass

The depth of penetration of laser radiation into the material, obtained in the experiment and measured by the micro-interferometer MII 4, is presented as the function of the power of laser radiation in Fig. 2. Point curve presents the depth of penetration of the radiation into the material as the calculation result of expression (6).

Following that, the thermal diffusivity, as a physical quantity that characterizes the rate of temperature change of material in non-equilibrium thermal processes, allows to fully consider non-linear change of thermal properties of materials, that caused by changes of physical, mechanical, chemical, and esthetic properties of materials due to the heterogeneity of the microstructure, caused by volume uncertainty and multivariance of implementations of the characteristics of applied material.

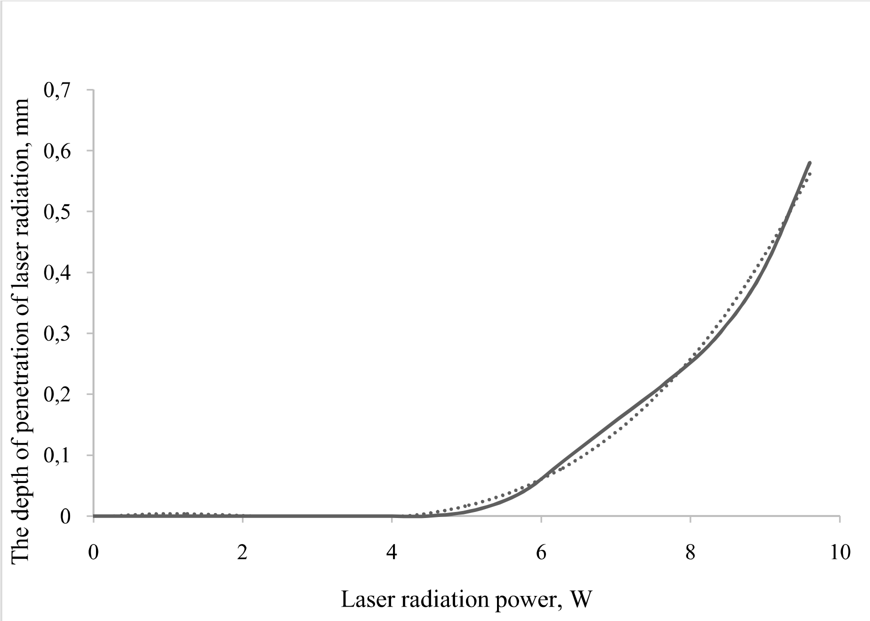

Figure 2. The estimated depth of penetration of laser radiation into the material (point curve) and obtained in the experiment one (solid curve)

Results and Discussion

Highlighting of the complex index greatly simplifies the choice of laser radiation parameters, since it allows to create an Atlas of temperature diffusivities of materials as a set of rules for the location and naming of materials, that rules establish the order of arrangement of materials in accordance to temperature diffusivities of materials so the more similar material properties are, the closer materials should be located to each other, and establish method of indicating of the material location in the sequence of temperature diffusivities.

The using of the proposed Atlas will simplify the choice of numerical coefficients in the expression (6). As a result of mathematical calculations, analysis and expert survey it is obtained that the depth of penetration of laser radiation into the material of 0.3–0.5 mm is necessary for most sharp and clear image. This is enough to obtain a stable contour of cutting, high-contrast images and patterns, a necessary adhesion to stain the image. On the basis of the analytical function, there are next selected modes of laser system for imaging of the material [7]:

– the power of laser radiation of 8.32 W;
– the laser engraving speed of 18 cm/s;
– the resolution of 500 dpi;
– the pulse frequency of 1000 Hz;
– the diameter of the focused laser beam on the material surface of 0.1 mm;
– the angle of incidence of the laser beam 0°.

Conclusions

Thus, the theory and practice of laser material processing confirm the possibility of efficiency increasing of laser technologies application for identification imaging of artistic and industrial products of wood, natural and artificial leather, bone, glass, ceramics, organic glass, plastic, metal and other materials by considering of correlation and regression relationship between technological modes of laser equipment and surface characteristics of industrial products.

The practical significance of the work is determined by the developed proposals applicable to the solution of topical problems of establishing of individual modes of laser processing for the decorative processing of materials considering multiple versions of realization of technology modes and considering indeterminacy of specific properties of material. The proposed method allows to preserve the unique natural pattern, to successfully compensate the existing natural heterogeneity of material and to provide consistently high results in industrial production of high-artistic exclusive products.

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