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Establishing of the Laser Engraving Modes for Decorative Processing of Glass Products

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Abstract. The relationship between properties of industrial products and features of the laser processing technological modes are researched. The simulation model for execution of the laser engraving operating modes is developed. The analytical expressions, that show the relationship between the laser engraving modes and optical properties of glass and allow to increase the efficiency of laser technology application and to choose more suitable laser parameters considering microstructure, chemical composition and mechanical properties of material, are derived.

***Keywords*:** instrument engineering, glass, laser technology, engraving, optical properties, industrial products

INTRODUCTION

Glass is modern, functional and esthetic material that has a set of useful properties and natural beauty, so, thanks to that, the glass products are demanded in various spheres of human activity. Broad using of glass is caused by the unique and peculiar combination of physical and chemical properties, that combination is not typical to any other material. Glass is widely applied in industrial production, medicine, aircraft and astronautics, construction, holography, trading, advertising, decoration works, etc.

The application of glass is plural depending on its properties: in instrument engineering glass is applied in variable and constant capacitors, in self-induction coils, in vacuum devices, for the production of substrates for micro-modules of printed circuit boards, small capacitors, high-voltage and high-frequency insulators, devices with ultraviolet radiation, light cells , optical fibers of computers, glass fibers, optical filters, including variable transmission filters, films, for example, glass films that have thickness of 5–100 microns are applied for insulation of electric machines. Glass is applied for production of protective glasses for devices' protection from mud, mechanical damage, dust and liquids under the ambient temperatures of -60 till +60 °C.

Because of low mechanical durability, fragility, presence of internal tension and high requirements to a surface, drawing texts, images, barcodes, scales, limbs, etc., has certain difficulties. Laser processing including laser engraving and laser cutting gives to glass products high appeal. Thanks to creation of reliable and rather economic laser equipment in the 70–80th of 20th century, laser technology of materials processing had appeared as a new industrial technology. That allows to change flexibly the images on a product surface with the maximum using of material without readjustment.

Laser engraving has a number of great advantages in comparison with other types of imaging such as cutting, grinding, cutting, abrasive-jet, chemical, ultrasonic, arc, electric arc and ion engraving.

Laser engraving doesn't require high qualification of personnel, it allows to perform contactless processing of billets, so that allows to minimize the internal thermal-mechanical tensions, to reach the smooth and stable contour of cutting, the high-artistic contrast dark look of images, the minimum rounding radius of angles of cutting (0.1–0.3 mm) and gives a chance of simultaneous engraving and cutting of material, so that decrease the positioning error and the additional processing. At the same time new design properties of an engraving which not to reach machining or other types of an engraving turn out, and completely digital chain of processes of production with high precision of repeating is created, thanks to virtual process of display, visual representation of structures is reached in three-dimensional space. Production of special templates of structures is performed by using of the graphical software. By scanning of the available samples and by its transferring to gradation of gray, the laser imaging and other types of imaging can be combined, the simplified application of combined materials to products and the direct imaging of complex three-dimensional structures are possible with high efficiency and high performance of production and minimum costs of time for starting of new production [2].

Widespread in industry production laser technologies are applied rarely for engraving of glass due to lack of approved methods of selecting of processing modes. The high investment costs for a robotic laser engraving machine require achieving of a higher consumer qualities of a new design of an art-industrial product to prove these investments. Since laser engraving is a rather new method with higher requirements to tolerances of machined surfaces, not all techniques of engraving are suitable, there are specific technologies that should be used.

Establishing of the processing modes for glass for reaching of desirable result has some features. The most widespread technique of action in that case is experimental operation of laser machine in all possible modes, using work material, that will be used for production of real products. Disadvantages of that technique are unreasonable using of a large number of work materials with spending service life of laser equipment and time for performing of such operations and making of test programs.

As a result of the performed operations, a proposition of establishing of laser engraving modes are developed for processing of glass products in a broad variation range of material characteristics in case of multiple variants of the choice of possible operating modes combinations. The apparatus of probability theory, mathematical statistics, mathematical modeling and the theory of stochastic functions is applied to solve that problem.

INFORMATION THEORY

Laser operation is based on thermal interaction between light and absorbing medium. The propagation of light in material medium can be divided into four interrelated processes.

1. The reflection of light.
2. The absorption of light depends on its initial intensity, on the thickness of medium that light is passing throw, on the wavelength of the absorbing light and on the coefficient of absorption. If light isn't being absorbed, there is no any interaction between light and material. When photon is being absorbed by a target-molecule, all its energy is being transferred to that molecule and is being spent for a heat and/or for a luminescence.

3. Scattering of light. The phenomenon of scattering is important because it quickly decrease the radiant flux density, impacting on a material. Scattering is decreased with increasing of wavelength, so longer waves of light are ideal way to deliver energy in deep structures of material.

4. Penetration of light. Light penetration depth in deep structures, as well as intensity of scattering, depends on wavelength. Short waves (300–400 nanometers) are intensively scattered and don't penetrate more than 100 microns. But long waves penetrate deeper because that waves are scattered less.

Interaction between laser radiation and material is adequately described by thermal model according to that model the quantity of energy for laser processing significantly depends on optical properties of materials. Key physical parameters of laser, that determine impact of quantum energy to one or the other target, are the generated wavelength, the radiant flux density, the time of impact, the angle of incidence and the quality of a laser beam [3].

Establishing of the laser engraving modes for processing of glass products in practice is performed on the grounds of results of performed experiments; it's low-effective and is accompanied by great costs. The execution of operating modes with simulation model is more progressive.

Relationship between laser engraving modes and optical properties of glass can be described generally by the following expression:

$$R_i\left(Y_i, Y_2, \ldots, Y_i\right) = f\left[R_j\left(Y_i, Y_2, \ldots, Y_j\right)\right],$$

where R – are the parameters of the laser engraving modes; R_i – are the changes of parameters of optical properties of glass; X_1, X_2, …, X_i – are the types of optical properties of glass; Y_1, Y_2, …, Y_j – are the levels of the laser engraving modes; i – is the quantity of optical properties of glass; j – is the quantity of levels of the laser engraving modes, f is the function of the physical parameters of the laser, such as the generated wavelength, the radiant flux density, the time of impact, the angle of incidence, that define interaction between quantum energy and material, and the properties of optical glass such as the microstructure, the chemical composition and the mechanical properties.

Often laser engraving needs to be applied on a finished product when the type of glass of product is unknown. Let's carry out the analysis factors that influence on optical properties. The thickness deviation in a batch of similar products (from 5 % to 30 %), the tendency to surface damages due to a hardness deviation (to 5 %), the emergence of internal tension during the forming operation that leads to the further emergence of microcracks, the high sensitivity to the cluster of tensions influence on the transmission of light. It determines deviations of density, hardness, thermal resistance, thermal conductivity, viscosity, thermal capacity, temperature of a softening, melting point, etc. These properties become a random variable in each case, that's why optical properties of glass become a stochastic function in each specific case of application. Existence of correlation relationships between optical properties of glass and microstructure, chemical composition and mechanical properties of glass can be provided by the expression

$$R_i\left(X_1, X_2, \ldots, X_i\right) = \gamma\left(Z_1, Z_2, \ldots, Z_k\right),$$

where R_i – are the changes of parameters of optical properties of glass; X_1, X_2, …, X_i – are the types of optical properties of glass; i – is the quantity of optical properties of glass; Z_1, Z_2, …, Z_k – are the characteristics of microstructure, chemical composition and mechanical properties of glass; k – is the quantity of the characteristics of microstructure, chemical composition and mechanical properties of glass.

Any stochastic function can be aligned, i.e.to reduce to form when its expected value is equal to zero. Therefore only the aligned elementary stochastic functions will be considered further.

Using the method of canonical representations, stochastic function will be presented as the sum of so-called elementary stochastic functions

$$W(x) = V \cdot \beta(x),$$

where $W(x)$ is the stochastic function, V is the regular random variable, $\beta(x)$ is the regular (non-stochastic) function.

Taking in mind that the deviations of density, hardness, thermal resistance, thermal conductivity, viscosity, thermal capacity, temperature of a softening, flame temperature have normal (or Gaussian) distribution, we'll perform modelling of normal random value on a ground of the central limit theorem:

$$V = \mu + \sigma \cdot \left(\sum_{i=1}^{12} P_i - \sigma \right),$$

where μ – is the average of the normal distribution; σ – is the standard deviation; P – is the random basic number that generated by the random number generator [4].

$\beta(X)$ will be described as regular (non-stochastic) function of coefficient of transmission (transparency, %) in ultra-violet, visible and near-infrared spectral ranges from wavelength of optical radiation.

The developed model is used for establishing of the laser engraving modes of glass with unknown characteristics.

To determine analytical expressions, the method of interpolation and extrapolation and the least-squares method of approximation are applied considering condition:

$$F = \sum_{i=1}^{n} \left(y_i - \beta(x_i) \right)^2 \to \min,$$

where F – is the minimized function; y_i – are the empirical points of statistical dependence; $\beta(x_i)$ – is the analytical functional dependence.

In case of the directed transmission, scattering can be neglected and the radiant flux on the sample is divided into three components: reflected, absorbed and transmitted one. Considering that the reflected flux is about 5–7 % for all types of glass, the transmitted flux can be calculated according to the obtained expressions. The difference between the energy of the incident flux, the energy of the reflected flux and the energy of the transmitted flux allows to calculate the absorbed energy, consumed for heating.

To choose the wavelength of a laser radiation, the function of transparency from wavelength is used. Determination of this functional dependence is performed on a ground of statistical data from the literature. In the Fig. 1 charts 1 and 2 of boundary cases of dependence of transparency on the wavelength of optical radiation of the main brands of glass are submitted.

Based on the conducted researches approximation is selected by polynomial function of the second order.

$$\beta(\lambda) = -194.57\ \lambda^2 + 296.97\ \lambda - 19.961,$$

$$\beta(\lambda) = -127.41\ \lambda^2 + 249.33\ \lambda - 25.76,$$

where $\beta(\lambda_i)$ – is the analytical functional dependence of the coefficient of transmission from the wavelength of optical radiation; λ – is the wavelength of optical radiation.

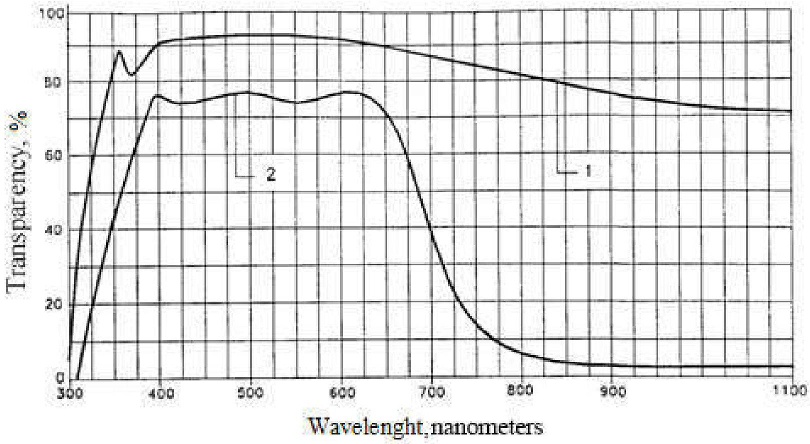

Figure 1. Spectral characteristic of transmission of various glasses:
1 is for a usual windowpane, 2 is for glass with a low-emission coating [5]

DESCRIPTION OF AN EXPERIMENT

The obtained expression describes the boundary values of the changes of light transmission of glass, while changing the wavelength of the laser radiation. The most optimal for the case in question is a CO_2 laser, the emission wavelength of 10.6 μm, controlled by the computer.

For engraving the laser engraver of the Speedy series of Trotec (Austria) with use of Corel Draw, JobControl software product is chosen.

RESULTS AND DISCUSSION

Analysis and expert survey showed that to obtain the most clear and high-contrast images to obtain a depth of penetration of laser radiation in an glass of 0.3–0.5 mm. is enough to obtain a stable contour cutting, highly contrasting dark view of paintings and patterns, the necessary adhesion during filling of the image dye.

Given the functional relations between the modes of operation of the laser system, the maximum absorption of light energy glass, optimum performance, set the modes of laser

Given the functional relations between the modes of operation of the laser system, the maximum absorption of light energy of glass, optimum performance, set the modes of laser engraving:

– Laser output power of 11.4 watts.
– Laser engraving speed of 27.0 cm/h.
– Resolution of 500 dpi.
– Pulse frequency 1000 Hz.
– The diameter of the focused laser beam on the material is 0.1 mm.
–The angle of incidence of the laser beam 0°

To check the correctness of application of the developed methodology for setting the modes of interaction of laser radiation with a glass reproduce halftone gray scale [GOST 24930-81. Facsimile equipment gray scale. Technical requirements] from white to black, when changing the laser output power from 2 to 12 W, the laser engraving speed from 10 to 180 cm/sec., resolution from 100 to 1000 dpi., the frequency of pulses from 500 to 1000 Hz, the diameter of the focused laser beam on the material from 0.05 to 1.0 mm. the angle of incidence of the laser beam from 45° to 90°, and combinations of these modes.

CONCLUSIONS

Successful methods of compensation available natural heterogeneities of the material and technological possibilities that provide consistently good results in the case of industrial production of highly exclusive products that help to outline the directions of continued research to improve the quality of the products high quality consumer products.

Methods of successful compensation of the available natural heterogeneities of material and technological capabilities of ensuring steadily good results are found in case of industrial production of highly artistic exclusive products, the directions of continuation of researches are planned.

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