The Laser Engraving in Decorative Processing of Organic Glass

A.V. Usoltseva

Kalashnikov Izhevsk State Technical University, Izhevsk, Russia
E-mail: Ajieksa_oo@mail.ru

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Abstract. Conducted work on development of a methodology for setting the modes of the laser engraving in decorative processing of plexiglass under uncertainty characteristics of the material used and of providing multiple choice of possible combinations of operating modes. Used the results from the mathematical analysis and the expert survey. The study derived a universal laser engraving for various brands of organic glass to provide a stable contour cutting, highly contrasting dark view of paintings and patterns, the necessary adhesion during filling of the image dye.

Keywords: plexiglass, organic glass, engraving, laser technology, laser engraving

Plexiglass is modern, functional and aesthetically pleasing material, which has many useful properties, natural beauty, and the made from it products are popular and have demand in the most various spheres of human activity. It is widely used in industrial production, medicine, Commerce, advertising, in complying with such finishing works, etc.

Primary brand of Plexiglass, used in industrial manufacturing, is a technical organic glass marks top and TON (GOST 17622-72, THE 2216-271-05757593-2001), which is a plasticized and plastifici) polymer of methyl methacrylate produced by the method of block polymerization, (formula [- $CH_2C(CH_3)(COOCH_3)$ -]n). Plexiglass is produced by the form of transparent sheets with a perfectly glossy surface on both sides, translucent, colorless or colored, including smoky, opaque white, black, any color. It is widely used in machine tool, machinery, automotive, instrumentation and other industries, when you perform exterior jobs [1].

Due to the high aesthetic requirements to the surface, low mechanical strength, the presence of internal stresses, the treatment of the Plexiglas causes some difficulties. High attractiveness of the products of Plexiglas attached to laser processing, including gravity field and cutting. Throught to the creation of reliable and low cost laser equipment in the 70–80s of the last century was reappear a new technology of industrial – it is the laser materials processing technology. This allows changeover to flexibly change applied to the product image at the maximum use of the material.

Compared with other types of engraving: cutting, grinding, cutting, striking, abrasive blast the graving, physic-chemical, ultrasonic, electric-arc, electron-ion laser engraving has a some of significant advantages. Laser engraving does not require high staff qualification, used for contactless processing of blanks, there are no internal stresses, is obtained a smooth and stable contour cutting, highly contrasting dark view of paintings and patterns, a minimum

radius of rounding of corners cutting (0.1–0.3 mm), it is possible to apply simultaneous engraving and cutting material, there is no positioning error, there is no additional processing.

Organic glass is superior to most numbers of plastics by its extreme transparency, differing light transmission in a wide range, including ultraviolet, visible and part of near infrared region of the spectrum. For light transmission in the visible region of the spectrum, it is second only to quartz glass, letting in almost 100 % of visible light. This makes good paintability plexiglass in various colors. Apply the ability to pass ultraviolet rays Plexiglas is superior to ordinary silicate glass, some yielding quartz glass.

Choosing between the modes of laser processing for work by organic glass to produce an acceptable result arise some the numbers of peculiarities caused by the uncertainty of material properties and the many variability combinations of the selected technological regimes. The most common method of action in these cases is using of all modes a working material which will be used to manufacture real products. The disadvantage of this methodology is unreasonable use of a large amount of working material, or some numbers of the products, the service life of laser equipment, time to conduct these works and the compilation of the test programs.

The aims of this study is to develop methods of setting the modes of the laser engraving in decorative processing of organic glass under uncertainty characteristics of the material used and of providing multiple choice of possible combinations of operating modes. To solve this problem we use the theory of probability, mathematical statistics, mathematical modeling, theory of random functions.

The main physical parameters of the laser which determine the effects of quantum energy on a test sample are the length of the generated waves, the energy flux density, exposure time and the angle of incidence of the laser beam [3].

The relationship between the modes of the laser engraving and optical properties of organic glass in General can be described by the following formula:

$$R\,(Y_1, Y_2, \ldots, Y_i) = f\,\{R_i\,(X_1, X_2, \ldots, X_i)\},$$

where R – parameters of laser engraving, R_i – parameter changes of the optical properties of Plexiglas, $X_1, X_2, \ldots, X_i$ – types of the optical properties of Plexiglas, $Y_1, Y_2, \ldots, Y_j$ – levels of laser engraving, i – number of the optical properties of Plexiglas, j – number of levels of the modes of laser engraving, f – the function that links physical parameters of the laser.

Often the laser engraving should be applied to the finished product when the brand Plexiglas, from which it is made, is unknown. The existence of correlations between the optical properties of Plexiglas and microstructure, chemical compositions and physic-mechanical properties of Plexiglas can be represented by the expression.

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

where R_i – is changing the parameters of the optical properties of Plexiglas, $X_1, X_2, \ldots, X_i$ – types of the optical properties of Plexiglas, i – number of the optical properties of Plexiglas, $Z_1, Z_2, \ldots, Z_k$ – the characteristics of the microstructure, chemical composition and physic-mechanical properties of Plexiglas, k – the number of microstructure characteristics, chemical composition and physic-mechanical properties of Plexiglas.

Any random function can be centered, that is, lead to a form when its mathematical expectation is equal to zero. Therefore further displayed only centered elementary random functions.

Using the method of canonical decomposition of random function pre-suppose as a sum of so called elementary of random functions:

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

where $W(x)$ – is a random function, V – normal random variable, $\beta(x)$ – is regular (nonrandom) function.

Assuming that the deviation of density, hardness, heat resistance, thermal conductivity, viscosity, heat capacity, softening temperature, temperature of combustion have a normal (or Gaussian) distribution, conduct a simulation of normal random variable based on Central limit theorem:

$$V = \mu + \sigma(\sum_{i=1}^{12} P_i - 6),$$

where μ – the mean of normal distribution, σ – standard deviation, P – random base number, for the generation which used the gene-operator random numbers [4].

Ordinary (non-random) function $\beta(x)$ describe the dependence of the transmittance (light transmission, %) in the ultraviolet, visible and near infrared spectral regions on the wavelength of optical radiation.

To determine analytical expressions applied the method of interpolation and extrapolation using the approximation least-squares adjustment with condition:

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

where F is the minimized function, y_i – an empirical point of statistical dependence, $\beta(x_i)$ – analytical functional dependence.

For directional transmission, when the dispersion can be not included, the luminous flux incident on the sample, divided into three components: reflected, absorbed and missed. Assuming that the reflected flux in all varieties of Plexiglas is 5–7 %, missed flux is calculated according to the obtained expressions. The difference between the energy of the incident flow and the reflected and missed streams will allow us to calculate the energy absorbed substance used for heating.

To select wavelength of laser radiation used for the light transmission dependence on the wavelength. The definition of this functional dependence was conducted on the basis of the obtained and the literature cited in the statistical data (Figures 1 and 2).

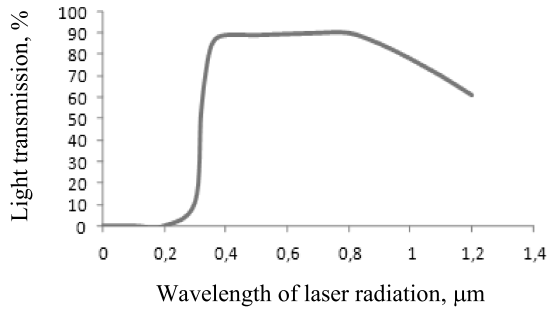

Figure 1. Chart based light transmission of the wavelength of the radiation to the PMMA block, plasticized by addition of DBP

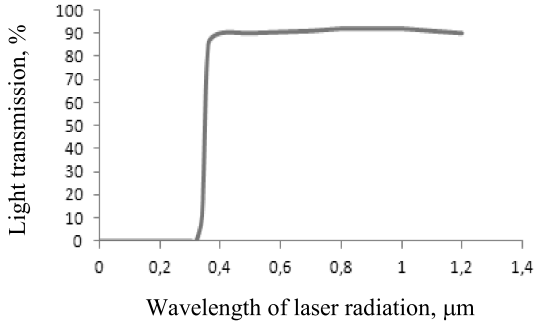

Figure 2. Chart based light transmission of the wavelength of radiation for unplasticized PMMA stabilized by addition of FS

On the basis of the conducted studies the approximation polynomial function of second order:

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

$$\beta(x) = -127{,}41x^2 + 249.33x - 25.76,$$

where $\beta(x_i)$ – analytical functional dependence of transmittance on wave length of optical radiation, x – wavelength optical radiation.

The obtained expression describes the boundary values of the changes of light transmission of Plexiglas, 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. Selected for engraving laser engraver Speedy series of companies Trotec (Austria) using the software CORELDRAW, JOBCONTROL.

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 organic 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 by organic 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 90°.

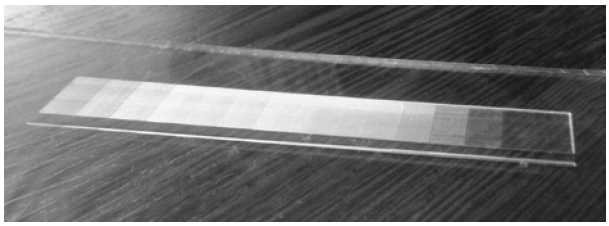

Figure 3. Half-tone wedge from white to black

To check the correctness of application of the developed methodology for setting the modes of interaction of laser radiation with a Plexiglas reproduce halftone wedge [5] from white to black, Figure 3 when changing the laser output power from 2 to 12 W, the laser engraving speed from 10 to 180 cm/s, 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 900, and combinations of these modes.

The practical significance of the work is determined by the developed proposals applicable to the solution of actual tasks of the job of laser engraving for decorative processing of organic glass with a lot of variants of implementations in the face of uncertainty of the material used. Promising the continuation of works in relation to other materials.

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