INFORMATION SYSTEMS AND INNOVATIVE TECHNOLOGIES IN PROJECT AND PROGRAM MANAGEMENT

Collective monograph edited by
I. Linde, I. Chumachenko, V. Timofeyev

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INFORMĀCIJAS SISTĒMAS UN INOVATĪVAS TEHNOLOĢIJAS PROJEKTU UN PROGRAMMU VADĪBĀ

Kolektīvas monogrāfija

I. Linde, I. Chumachenko, V. Timofeyev

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The monograph presents the achievements of Ukrainian scientists on enterprise management, the use of economic and mathematical modeling, information technologies, management technologies and technical means in the field of enterprise functioning and development and project management at enterprises.

The publication is recommended for professionals in the fields of economics, information technology, project and program management - for undergraduate and graduate students, as well as academics and teachers of higher education.

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CONTENT

22. VISUAL MONITORING OF THE BREAK SURFACE OF THE INSTALLATION CONNECTION OF ELECTRONIC EQUIPMENT

Nevliudov I., Starodubcev N., Demska N., Omarov Sh.

The progress of modern technology, expansion of the range of tasks assigned to the system control, high accuracy requirements, noise immunity, speed, etc. has led to increasing complexity of electronic technology and the creation of complex systems designed to solve a number of important tasks. In turn, the complexity of the instrument may lead to a sharp reduction in its reliability, which in some cases is dangerous, for example, when used in medicine, the military, while space research, transport, etc. To provide diagnostic functions and subsequently the functions of the prognostics of technical condition of electronic devices and their critical components (e.g., a flexible switch structures) it is necessary to create an effective tool for monitoring the status of the product. The aim of this study is to test the theoretical provisions on a diffuse scattered light surface tear by experimental studies of the spectrum of spatial frequencies of images of the surface of rupture. This paper proposes a method of obtaining images of the analyzed surface with its reflected light flux, providing the quantitative estimate of the amount of diffuse reflective sites, using the software. It is assumed that display physical and chemical processes, for their visual perception greatly enhance monitoring capabilities and will provide recommendations on the optimal scheme of optical control of surface gap, which will greatly reduce the complexity of control operations.

Requirements for electronic equipment (EE) products are constantly growing due to the tightening of their operating conditions. At the same time, there is a serious problem of providing qualitative indicators of flexible components, since they can be subjected to a large number of destabilizing factors at all stages of the life cycle [1]. So, for example, modules installed on moving objects – cars, airplanes, rockets, etc. during operation can be subjected to intense mechanical stress-shock, vibration, linear overload [2].

The implementation of the technological process for the manufacture of EEs is necessarily accompanied by the appearance of products of physicochemical reactions, mass transfer, and restructuring of the medium structure. This allows the interpretation of the results of the process as the formation in a certain place during a certain time of a substance with new properties, which ultimately determine the parameters of EE. Similar phenomena are observed during the operation of EE, here the appearance of a new substance can be interpreted as the result of degradation processes necessarily present in the materials and structures of EE, including rupture of the surface of the conductor [3].

To characterize such processes, sizes, shape, volume, and other geometric parameters of the observed images can be used. An example of a fairly effective use of figurative analysis is the solution of pattern recognition and classification problems based on a geometric interpretation of recognition processes, which leads to the possibility of using the display of patterns and classes of objects of various natures in the feature space in the form of geometric shapes corresponding to recognizable patterns. In this case, the size, shape, volume, relative position, other geometric parameters of the observed images are also used to characterize recognized objects. [3].

The use of figurative analysis to recognize the state of objects of various natures on the one hand, and the presence of certain states of the environment in which the analyzed processes take place, makes it possible to use the same principles for figurative analysis of processes. The implementation of these principles is possible if the "geometric" features and the geometric images formed in the space of these features carry information about the physical nature of the process.

Thus, we can make an assumption about the possibility of using for analysis of processes the information obtained when evaluating the properties of the formed reacted (RS) and unreacted substance.

The absolute values of the distribution of RS and the heights of the roughness of the gap (RG) in a complex way depending on the conditions of formation of the connection, and therefore they can only be given a relative estimate. Since the RG profile, specified in a certain direction, sufficiently characterizes its geometry, we can estimate the parameters of the correlation function of the RG profile in the direction of the axis x. The possibility of a linear approximation depending on the values of the RS distribution and the height of the RG irregularities during relative estimation give rise to the assumption of the identical behaviour of these quantities and the corresponding correlation functions when considering their dependence in the coordinate system of the RG profile. The expansion of a random function $W(x)$ in a Fourier series leads to the expression

$$W(x) = \int_{-\infty}^{+\infty} \varphi(\nu) e^{ix\nu} d\nu \,. \quad (1)$$

The spatial correlation function of the distribution of the RS concentration along the axis x will be determined by the expression

$$R_{\tau} = \overline{W(x)W(x+\tau)} = \int_{-\infty}^{+\infty}\int \overline{\varphi(\nu)\varphi^{*}(\nu')} e^{ix(\nu-\nu')} e^{i\nu\tau} d\nu d\nu' \,. \quad (2)$$

If we assume that the value x is not allocated in relation to other values, then the spatial correlation should not depend on x and is only a function τ. But the right-hand side of expression (2) will not depend on x only if the integrand is nonzero only when $\nu = \nu'$, i.e. if the function $\overline{\varphi(\nu)\varphi^*(\nu')}$ has the form

$$\overline{\varphi(\nu)\varphi^*(\nu')} = \varphi^2(\nu)\delta(\nu - \nu'), \tag{3}$$

whence

$$R_\tau = \int_{-\infty}^{+\infty} \varphi^2(\nu) e^{i\tau\nu} d\nu. \tag{4}$$

Expression (4) is a spatial analogue of the well-known Wiener-Khinchin theorem that relates the temporal and spectral characteristics of random signals using the Fourier transform. The function $\varphi(\nu)$ is the spatial-spectral characteristic of the distribution of the RS along the axis x. The relationship between $\varphi(\nu)$ and R_τ is given by the relation

$$\varphi^2(\nu) = \int_{-\infty}^{+\infty} R(\tau) e^{i\tau\nu} d\tau. \tag{5}$$

To evaluate this characteristic, it is necessary to find the spatial correlation function of the distribution of the concentration of RS [4] along the axis x.

Distribution of the concentration of RS is carried out in accordance with the laws of statistical physics, the main provisions of which assume the presence of a fluctuation component in the description of phenomena and parameters that characterize the state of a thermodynamic medium consisting of microparticles of RS [5]. In the process of activation, these microparticles acquire greater mobility; this gives reason to use here the idea of the processes occurring in a liquid consisting of RS particles. From the point of view of statistical physics, the behaviour of such a system is characterized by:

– Hamiltonian $H(X)$ as a function of variables X defining the microscopic state of the system;

– the module of the canonical distribution Θ that determines the average energy that falls on one degree of freedom (for a statistical mechanical system $\Theta = kT$, where k is the Boltzmann constant, T is the absolute temperature);

– forces a acting in the direction of the generalized coordinates of the system $q(X)$.

According to the main provisions of the Gibbs theory for generalized coordinates of the system

$$\frac{\partial \bar{q}}{\partial a} - \overline{\frac{\partial q}{\partial a}} = -\overline{\frac{1}{\Theta}\left(\frac{\partial H}{\partial a} - \frac{\partial \overline{H}}{\partial a}\right)(q - \bar{q})} . \tag{6}$$

If we distinguish two generalized coordinates $q_1(X)$ and $q_2(X)$, and forces a_1, a_2, acting in the direction of these coordinates, respectively, then we can introduce the Hamiltonian function

$$H(X, a_1, a_2) = H_0(X) + a_1 q_1(X) + a_2 q_2(X) . \tag{7}$$

Since the concentration RS is a macroscopic quantity characterizing the state of the medium and a function of the coordinates of the particles RS, it can be considered as a generalized coordinate, and for two points of the medium having a concentration, respectively W_1 and W_2 from expressions (6) and (7), putting in them

$$q\ (X) = q_1(X) = W_1(X), \qquad q_2(X) = W_2(X), \qquad \overline{\frac{\partial W_1}{\partial a_2}} = 0 ,$$

receive

$$\overline{(W_2 - \overline{W_2})(W_1 - \overline{W_1})} = -\Theta \frac{\partial \overline{W_1}}{\partial a_2} . \tag{8}$$

If the considered medium points are located at a distance τ from each other, then the left-hand side of (8), which, by definition, is the correlation moment of random variables W_1 and W_2, is equal to R_τ then

$$R_\tau = -\Theta \frac{\partial \overline{W_1}}{\partial a_2} . \tag{9}$$

For the system under consideration, the role of additional terms of the type $aq(X)$ in the Hamiltonian function can be performed by the quantity PV, where P is the pressure, and V is the volume. Because

$$V = \frac{N}{W} , \quad PV = \frac{PN}{W^2} W , \tag{10}$$

where N is the number of particles; force a will be determined by the expression

$$a = \frac{PN}{W^2} , \tag{11}$$

then

$$a_2\overline{W_2} - P_2 N_2 = 0 \tag{12}$$

and for a function $\phi = a_2\overline{W_2} = P_2 N_2$, according to the rules of differentiation of implicit functions

$$\frac{\partial \phi}{\partial P_2}\frac{\partial \overline{W_1}}{\partial a_2} = \frac{\partial \phi}{\partial a_2}\frac{\partial \overline{W_1}}{\partial P_2}, \tag{13}$$

receive

$$\frac{\partial \overline{W_1}}{\partial a_2} = \frac{1}{N_2}\overline{W_2}^2\frac{\partial \overline{W_1}}{\partial P_2} \tag{14}$$

Thus, from (9) and (14) it follows

$$R_\tau = -\frac{\Theta}{N_2}\overline{W_2}^2\frac{\partial \overline{W_1}}{\partial P_2} \tag{15}$$

Expression (15) reflects the fact that the correlation function is determined by the sensitivity of the process of changes in concentration at one point to pressure changes at another point. Pressure P_2 arises due to intermolecular interaction forces, the change of which affects the concentration of particles in the medium. The derivative $\partial \overline{W_1} / \partial P_2$ reflects the action of forces, the sources of which are molecules located at point 2, on molecules located at point 1 [6], therefore, the radius of action of these forces determines the correlation interval of the distribution of the RS and the resulting RG profile.

The interaction energy of two molecules is extrapolated by the empirical potential of Lennard-Jones

$$\Phi(\tau) = \frac{c_1}{\tau^{12}} - \frac{c_2}{\tau^6}. \tag{16}$$

The second term of this formula corresponds to the van der Waals forces, the extent of which is several molecular radii r. The behaviour of the Lennard – Jones potential makes it possible to estimate the dependence R_τ for a real medium and conclude that the correlation function decreases significantly at distances reaching several molecule radii, according to accepted estimates, more than 10^{-7} m.

In fig. 1 – 2, the process of forming the spatial frequency spectrum of the RG image is displayed. Figure 1 shows the estimated graphs of functions that reflect the above relationships between the Lennard-Jones potential $\Phi(\tau)$ and the correlation function R_τ , in Fig. 2 its Fourier image $\varphi^2(\nu)$ characterizing the spectrum of spatial frequencies of the image RG.

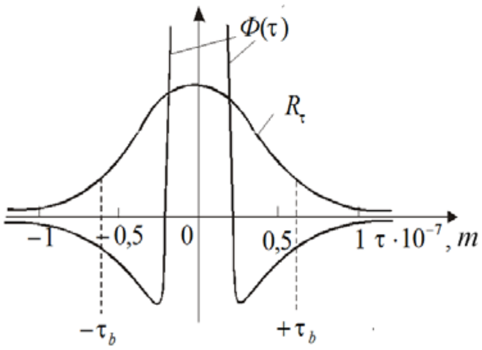

Fig. 1. The correlation function of the RG profile

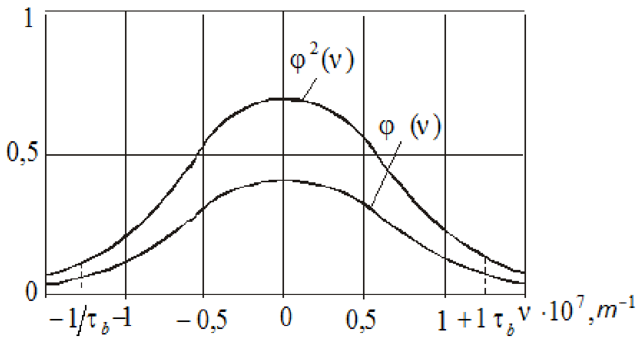

Fig. 2. The formation of the spectrum of spatial frequencies of the image RG

Considering that, by analogy with time signals, the width of the spectrum of spatial frequencies is inversely proportional to the width of the correlation function; we can conclude that there is white spatial noise in a wide range, from zero to $10^{-7}m^{-1}$ spatial frequency range.

The idea of the profile of RG can be obtained in the result of a mechanical simulation of the proposed mechanism for the formation of RG [7]. The simulation result is shown in Fig. 3. The initial data for the simulation was the dispersion of the distribution of irregularities along the axes x and z linked in a linear approximation with variance proportional to the concentration of RS. In view of the statistical independence of the processes of formation of RG on the distances, given estimates that more than 10^{-7}m, the choice of the variance, much larger, equal to 10^{-6}m, should not lead to significant errors in simulation results [8]. The presence of white spatial noise in the image RG gives grounds to conclude that when it is lighting it is possible to observe the diffuse dispersion of light and this can be used as a feature for recognition of RG in the analysis of the image.

Currently, technical vision systems (TVS) are used to solve such problems. The principle of operation here involves obtaining an image of the analyzed surface using the reflected light flux and the use of software that allows you to quantify the area of diffusely reflecting areas.

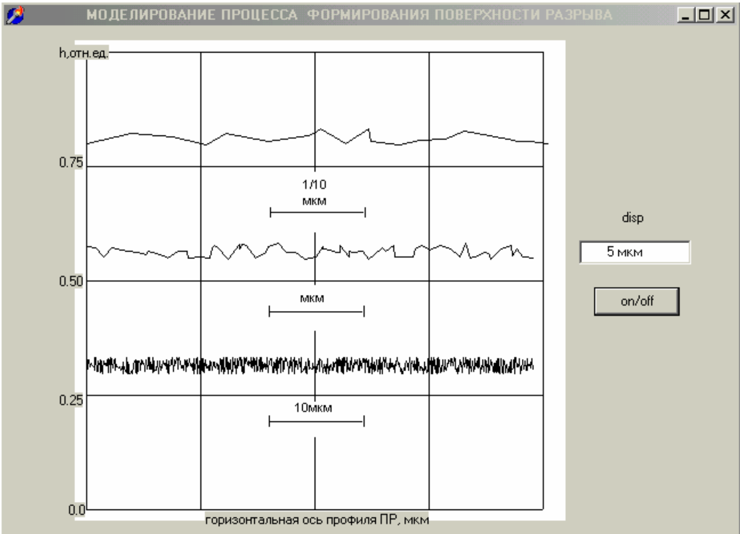

Fig. 3. RG profile modelling

It seems that an improvement in the detectability of RG can be achieved through a rational choice of the optical scheme of TVS and the use of optical filtering methods. Thus, the main objective of further research is to verify the theoretical positions obtained on diffuse light scattering RG by experimental studies of the spatial frequency spectrum of the RG image, which will make it possible to propose the optimal optical control scheme RG in order to evaluate the properties of the material forming the layer (MFL).

The analysis of the spectrum of spatial frequencies of the image of the initial surface. The complete separation of the light flux reflected by the analyzed surface into the mirror and diffuse components is fundamentally impossible, and the presence of the diffuse component in the spectrum of the initial surface can lead to deterioration in the detection of RG.

Thus, the use of a low-pass spatial filter makes it possible to increase the signal-to-noise ratio in a circuit where the mirror component reflected from RG light is used as a useful signal.

Experimental estimation of the spatial frequency spectrum of the RG image is presented. The experimental setup is shown in Fig. 4. The controlled surface of sample *1* was placed in the object plane of the optical circuit, which was aligned with the focal point of lens *2*. The parameters of the spatial low-pass filter *3*, mounted on the optical axis of the system in the focal plane of the lenses 2 and 4, were changed due to a change in the size of the light-transmitting square part.

The use of a video camera (cam), where a charge-coupled device (CCD) matrix combined with a PC personal computer was used as a photo converter, it was possible to implement an information processing system (IPS), and information output to the monitor. The use of a PC made it possible to implement a mode for measuring the illumination of the surface of a CCD by summing the

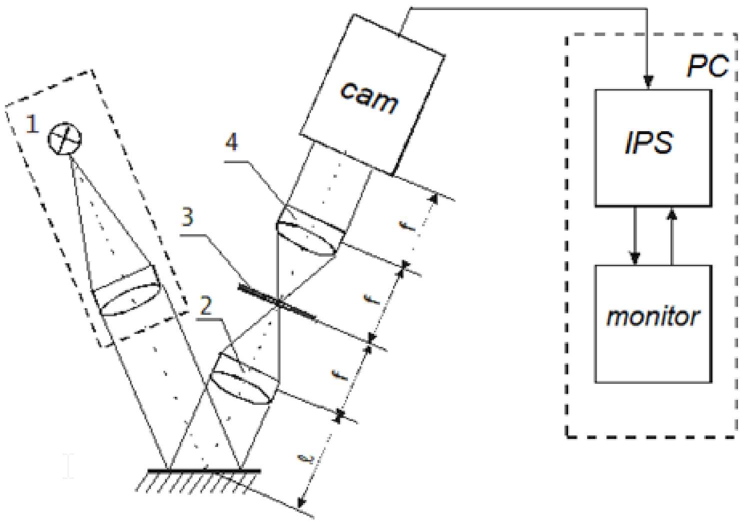

Fig. 4. The experimental setup

levels of signals received from each element of the matrix and normalizing the sum. The program developed for this provided for the transfer of the resulting image to the Image Editor of the Delphi software environment, digitization of the resulting pixel array, and further processing of the converted array in order to calculate and normalize the sum of its components. The image of the analyzed surface after inserting the image from the monitor screen into the Delphi project is shown in Fig. 5.

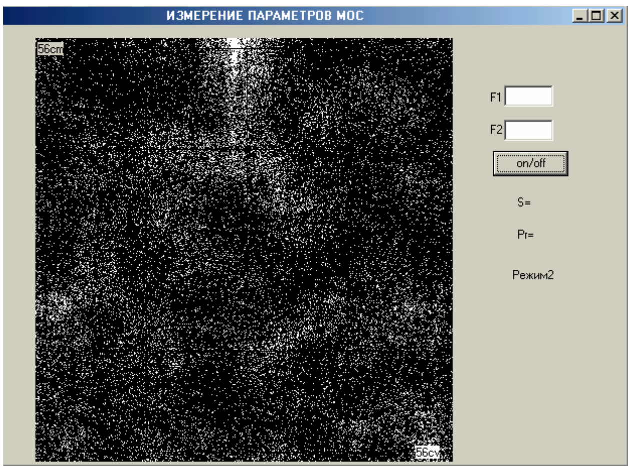

Fig. 5. Image of the analyzed surface of the gap

Having marked $F(x, y)$ the distribution of the complex amplitude of light in the plane of the object, we can obtain an expression for the distribution of the complex amplitude of light in the plane of the optical filter $f(\eta, \xi)$

$$f(\eta,\xi) = \frac{\exp[j\frac{k}{2f}(1-\frac{l}{f})(\eta^2+\xi^2)]}{j\lambda f}\int_{-\infty}^{\infty}\int F(x,y)\times\exp[-j\frac{k}{f}(\eta x+\xi y)]dxdy\,, \quad (17)$$

where k, l, f, λ – wave number, distance to the subject plane, focal length, wavelength of light, respectively.

When $l = f$ the image in the filter plane corresponds to the Fourier transform of the original image of the object. Assuming that spatial frequencies $F(x, y)$ occupy a range $\pm 1/\tau_b$, it can be approximated $F(x, y) = A$ in a rectangular region with sides $2\tau_b \times 2\tau_b$ and $F(x, y) = 0$ outside this region.

Designating $k/f \cdot \eta\tau = \alpha$, considering that when placing an object in the focal plane

$$f(\eta,\xi) = \frac{1}{j\lambda f}\int_{-\infty}^{\infty}\int F(x,y)\times \exp[-j\frac{k}{f}(\eta x+\xi y)]dxdy = \frac{1}{j\lambda f}A\left(\frac{\sin\alpha}{\alpha}\right)^2 \quad (18)$$

is a periodic function of α, and its period is equal to $\pm n\pi$, $n = (1,2,3,...)$ we can come to the equality

$$\frac{k}{f}\eta_b\tau_b = \pi . \quad (19)$$

Assuming that the main part of the spectrum is at its first maximum, this equality makes it possible to calculate the value of the upper spatial frequency η_b, and, consequently, the corresponding coordinate in the filter plane. Thus, the pattern that can be used to construct the spatial filter is a rectangular region transmitting light with the dimensions of the sides $2\eta_b \times 2\eta_b$ determined from equality (19). Calculation according to the formula (18) for $\lambda = 5\cdot 10^{-7} m$, $f = 5\cdot 10^{-2} m$, $\tau_b = 1/\nu_b = 15\cdot 10^{-6} m$ leads to the result $2\eta_b = 1{,}7\cdot 10^{-3} m$.

The energy of the radiation detected by the photo transducer can be determined by the formula $E = E_1 + E_2$, where E_1 the illumination due to the energy of light waves reflected from the analyzed surface, E_2 the additional surface illuminance of the CCD due to the reflected from the examined surface radiation caused by the beam divergence in the absence of a perfectly coherent source, and the presence of scattered radiation from the surfaces of the parts included in the installation design. Illuminance E_2 is essentially a source of error in the measurement of the useful signal caused E_1. To reduce uncertainty, to carry out the preliminary alignment of the illuminator. Thus, in the image plane was set perfectly reflecting surface, which gives the opportunity for coherent source to a wave of zero-order with a minimum value of the amplitudes of the harmonics. The axis system in the plane of the placement of the filter, install an opaque screen is rectangular in shape with dimensions $1{,}7\cdot 10^{-3}$m$\times 1{,}7\cdot 10^{-3}$m, that is guaranteed to have no effect on the results of the rays of the illuminator with the angle of divergence less than 1,7·10^{-2} rad. As shown by subsequent experiments, was able to pick up the illuminator, the divergence angle of the beam was less than 1, 3·10^{-2} rad. With a maximum window size of the filter achieved the minimum readings while measuring the light level of the surface of the CCD. Here were recorded the light levels at different filter settings and set the brightness of the light source. This level is then subtracted from the measurement results, thereby adjusting the above errors.

The well-known Parseval equality gives reason to use the expression

$$E_1 = \int_0^{\nu_b} \varphi^2(\nu) d\nu \tag{20}$$

and hence the calculation of spectral density by the formula

$$\varphi^2(\nu) = \frac{dE_1}{d\nu}. \tag{21}$$

The boundary frequency of the filter was determined by the dimensions of the sides of the square in accordance with expression (19) and varied from $2\eta_b = 1{,}7 \cdot 10^{-3}$ m to $2\eta_b = 20 \cdot 10^{-3}$, which corresponds to the interval of change τ from 15·10^{-6}m to 1,28·10^{-6}m. The correspondence between η_b and ν_b from (26) was determined by the formula $\nu_b = 2\eta_b / \lambda f$ and for the parameters of the given circuit $\nu_b = 8\eta_в \cdot 10^7 m^{-1}$.

Experimental studies were carried out on samples of soldered and adhesive joints, the design of which made it possible to carry out typical technological processes of surface preparation, to implement the necessary operations and modes, and to provide tensile testing and subsequent visual inspection of RG.

Figure 6 shows the dependence of the photoconverter illumination on the filter window area, measured at the above interval of change η_b, the scale of the corresponding filter pass band is also shown here.

To determine the function $\varphi^2(\nu)$ from discrete samples of the values of the derivatives (20), the least-squares method was used. For a given type of dependence $y = f(x)$, it allows to select its numerical parameters in the best way so that it reflects experimental data. The method is applicable for linear and nonlinear $y = f(x)$. Given the possibility of using a quadratic model in a limited frequency range, as an equation that allows you to determine the function $\varphi^2(\nu)$ from discrete samples, we can take the expression

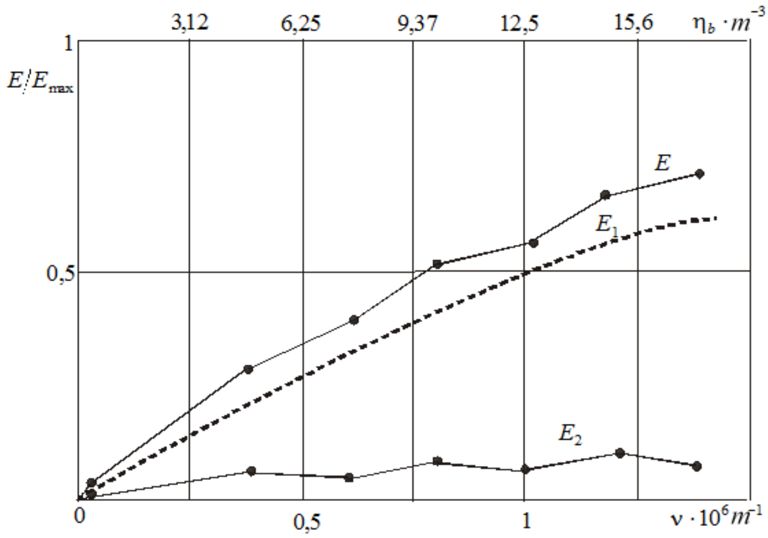

Fig. 6. The dependence of the illumination of the photoconverter on the area of the filter window

$$y = ax^2 + bx + c\,, \tag{22}$$

a, b and c can be determined by solving a system of normal equations. The calculations can be greatly simplified if the quadratic function is presented in the following form:

$$y = a_1\left(\frac{x-\bar{x}}{h}\right)^2 + b_1\left(\frac{x-\bar{x}}{h}\right) + c_1 \tag{23}$$

The values of the argument of this function are chosen equally spaced, i.e. $x_{k+1} - x_k = const = h(k = 1,2,\ldots,N-1)$, and its counting is carried out from the average value $\bar{x} = (x_1 + x_N)/2$ in integer parts of the step h for odd $N = 2M-1$ and in integer parts of the half step $h/2$ for even $N = 2M$. The parameters a_1, b_1 and c_1 functions (23) are calculated by the following formulas:

With odd $N = 2M-1$

$$a_1 = \frac{1}{3H_2(N)}\left[3\sum_{k=1}^{N} y_k (k-M)^2 - \frac{N^2-1}{4}\sum_{k=1}^{N} y_k\right], \tag{24}$$

$$b_1 = \frac{1}{H_1(N)}\sum_{k=1}^{N} y_k (k-M)\,, \tag{25}$$

$$c_1 = \bar{y} - \frac{H_1(N)}{N}a_1\,, \tag{26}$$

where $H_1(N) = N(N^2-1)/12$; $H_2(N) = N(N^2-1)(N^2-4)/180$.

With even $N = 2M$

$$a_1 = \frac{1}{12H_2(N)}\left[3\sum_{k=1}^{N} y_k(2k-N-1)^2 - (N^2-1)\sum_{k=1}^{N} y_k\right], \quad (27)$$

$$b_1 = \frac{1}{2H_1(N)}\sum_{k=1}^{N} y_k(2k-N-1), \quad (28)$$

$$c_1 = \bar{y} - \frac{H_1(N)}{N}a_1. \quad (29)$$

Figure 7 shows the observed spectral density of spatial harmonics of the RG image for several samples of compounds calculated from (22). The average non-uniformity of the spectrum in the frequency band $0{,}07\cdot10^6\ldots0{,}8\cdot10^6$ m^{-1} was 4.1%.

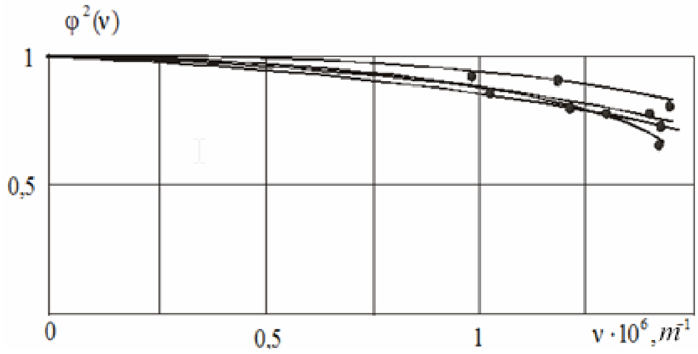

Fig. 7. Spectral density of spatial harmonics of the RG image

Noteworthy is the increase in spectrum non-uniformity with an increase in the upper limit of the range, which is a consequence of the limited size of the numerical aperture of the applied optical scheme, and the resulting attenuation of high-order harmonics that deviate significantly from the optical axis. This was confirmed by assessing the effect of misalignment of the optical and geometric axis of the lens system on the measurement results. A misalignment value of 5 mm led to a change in the results and significantly distorted the results for filters having a cutoff frequency of more than $1\cdot10^6 m^{-1}$.

Conclusions

Thus, the obtained results confirm the basic theoretical provisions on the diffuse light scattering RG, which confirms the proposed mechanism of RG formation, which provides a justification for the ability to evaluate the physicochemical activity of the MFL and the voltage corresponding to the true tensile strength of the MFL in a specific technological assembly and installation processes of electronic equipment.

The conducted studies made it possible to confirm the effectiveness of figurative analysis in some areas and to develop its main provisions that can be used to solve urgent problems of monitoring the production and operation of EE.

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