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CALCULATION OF THE PARAMETERS OF THE DISTRIBUTION OF THE LIGHTING INTENSITY IN THE INTERFERENCE AREA OF DYNAMIC OBJECTS DESIGNED FOR OPTICAL SYSTEMS

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ABSTRACT:

When making measurements in some industries, such as construction, heavy engineering, geodesy, increased requirements are imposed on the accuracy of measurements, which is achieved using interference methods, which necessitates the use of a video surveillance system to automate these measurements. The complexity of automatic decoding of interferograms and measurements of measurement information is due to the fact that the interference region, in addition to useful information, contains distortions and noises introduced by destabilizing factors, such as extraneous radiation sources, vibrations, atmospheric turbulence, dustiness, etc. This article is devoted to the calculation of the intensity distribution lighting in the interference region of dynamic objects.

KEYWORDS: interference, coherence, interferometer, video surveillance.

INTRODUCTION:

Currently, there are many optical systems for monitoring the position of objects using interference. The most promising are devices that use the spatial coherence of radiation, and are implemented in the form of prismatic blocks. Such devices have constant parameters, little dependence on the ambient temperature and other destabilizing factors. The distribution of the illumination intensity during interference is of interest for solving a number of practical problems, such as choosing the level of the sensitivity threshold of the device and limiting the upper level of illumination of the device receiving device. To accurately determine the values of these parameters, it is necessary to calculate in the form of a mathematical analysis the parameters of the distribution of the illumination intensity in the interference region of dynamic objects.

METHODS AND CALCULATION:

The mathematical foundations for describing the distributions of the radiation intensity fields of laser sources are quite complex and vary significantly depending on the type of the laser source, its design features, and some other factors. The intensity distribution in the interference region of a two-beam interferometer is defined as:

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\gamma_{12}(x,\tau), \qquad (1)$$

where I_1, I_2 are the intensity of the electromagnetic field generated by the first and second rays, respectively; γ_{12} - complex degree of coherence.

The complex degree of coherence in expression (1) for confocal resonators with rectangular mirrors is determined by the formula

$$\gamma_{12}(p,\tau)=\frac{\left\langle A_{1mn}(t+\tau)\cdot A_{2mn}(t)\cdot\exp\left\{i\cdot\left[\psi_{1mn}(1+\tau)-\psi_{2mn}(t)\right]\right\}\exp\left[i2\pi\nu_{mn}\tau\right]\right\rangle}{\left\langle A_{1mn}^2(t+\tau)\right\rangle\left\langle A_{2mn}^2(t)\right\rangle}\times$$
$$\times\exp\left[-\frac{x_1^2+y_1^2}{w_{mn}^2}\right]\exp\left[-\frac{x_2^2+y_2^2}{w_{mn}^2}\right]H_m\left(\frac{x_1\sqrt{2}}{w_{mn}}\right)H_n\left(\frac{y_1\sqrt{2}}{w_{mn}}\right)\times H_m\left(\frac{x_2\sqrt{2}}{w_{mn}}\right)\times \quad (2)$$
$$\times H_m\left(\frac{x_2\sqrt{2}}{w_{mn}}\right)H_n\left(\frac{y_2\sqrt{2}}{w_{mn}}\right)\exp\left\{i\left[\psi_{1mn}(p_1)-\psi_{2mn}(p_2)\right]\right\},$$

where x_1,y_1,x_2 and y_2 are transverse coordinates of points P_1 and P_2; w_{mn} - is the size of the radiation beam section in the analysis plane; H_m and H_n - are Hermite polynomials; ψ_{mn} (p)= $\psi_{1mn}(p_1)$-$\psi_{2mn}(p_2)$ - is the phase of the wave field equal to $\psi_{mn}(p)=-k_{mn}(x^2+y^2)/2R$; $k=2\pi/\lambda_{mn}$ - is the wave number; R - is the radius of the wave front of the beam in the plane of analysis.

As is known, the highest degree of temporal and spatial coherence is possessed by lasers, in which gaseous substances are used as active elements. They, as a rule, can be represented by some quantum generator with a resonator, which is equivalent to that in a real emitter and reduced to a confocal one described by the well-known expressions [1]

$$R_e=\frac{2L_p\sqrt{g_1\cdot g_2(1-g_1\cdot g_2)}}{g_1+g_2-2g_1\cdot g_2},$$

where R_e - is the equivalent confocal parameter; $g_1=l-L_p/R_i$ - generalized parameters of a real resonator; $w=w_0\sqrt{1+\xi^2}$ - the size of the beam section in an arbitrary plane; $w_0=\sqrt{\frac{R_y}{k}}$ - the size of the beam waist section; $\Theta=\frac{2}{\sqrt{R_y\cdot k}}$ - beam divergence angle; $R=R_э\frac{1+\xi^2}{2\xi}$ - the radius of the wave front; $\xi=\frac{2z}{R_y}$ - relative longitudinal coordinate; z - is the spatial coordinate measured along the propagation path of the laser beam from the waist plane (the plane where the beam cross section is minimal and the wave front is flat) to the observation plane.

Taking into account the introduced designations, subject to the analysis of the interference field in the far zone of the beam radiation, where L << R and $x_i^2+y_i^2=r_i^2$ <<R^2, expression (2) will be written as [2]

$$\gamma_{12}(p,\tau)=\frac{\left\langle A_{1mn}(t+\tau)\cdot A_{2mn}(t)\cdot\exp\left\{i\cdot\left[\psi_{1mn}(1+\tau)-\psi_{2mn}(t)\right]\right\}\exp\left[i2\pi\nu_{mn}\tau\right]\right\rangle}{\left\langle A_{1mn}^2(t+\tau)\right\rangle\left\langle A_{2mn}^2(t)\right\rangle}\times$$
$$\times\exp\left[-\frac{k_{mn}}{R_y(1+\xi^2}(r_1^2+r_2^2)\right]\cdot\prod_{i=1}^{2}H_m\left(\frac{x_i\sqrt{2}}{w_{mn}}\right)\cdot\prod_{i=1}^{2}H_n\left(\frac{y_1\sqrt{2}}{w_{mn}}\right)\cdot\exp\left[-i\psi_{12}(p)\right],$$

where the phase factor $\psi_{12}(\Theta)$ takes the form

$$\psi_{12}(p) = \frac{k_{mn} \cdot \left(r_1^2 - r_2^2\right)}{2R}.$$

Using the concept of spectrally pure radiation, which is applicable to the description of laser radiation, if during the formation of the interference field, the path difference between the interacting beams satisfies the condition

$$c \times \tau << \frac{c}{\Delta v},$$

where c - is the speed of light in the propagation medium; τ - is the time shift between the interfering beams, determined by the geometry of the measuring circuit; Δv - is the width of the spectral emission line.

The complex degree of coherence $\gamma_{12}(p,t)$ is represented as [3]

$$\gamma_{12}(p,\tau) = \gamma_{12}(\tau) \cdot \gamma_{12}(p),$$

where $\gamma_{12}(\tau)$ - is the degree of temporal coherence

$$\gamma_{12}(\tau) = \frac{\left\langle A_{1mn}(t+\tau) \cdot A_{2mn}(t) \exp\left\{i \cdot \left[\psi_{1mn}(t+\tau) - \psi_{2mn}(t)\right]\right\} \exp\left[i 2\pi v_{mn} \tau\right]\right\rangle}{\sqrt{\left\langle A_{1mn}^2(t+\tau)\left\langle A_{2mn}^2(t)\right\rangle\right\rangle}},$$

$\gamma_{12}(p)$ - degree of spatial coherence:

$$\gamma_{12}(p) = \exp\left[-\frac{k_{mn}}{R_э(1+\xi^2)}\left(r_1^2 + r_2^2\right)\right] \cdot \prod_{i=1}^{2} H_m\left(\frac{x_i\sqrt{2}}{w_{mn}}\right) \cdot \prod_{i=1}^{2} H_n\left(\frac{y_i\sqrt{2}}{w_{mn}}\right) \cdot \exp\left[-i\psi_{12}(p)\right].$$

The intensities I_i for each of the channels are determined by the losses during the passage inside the device. For the first of the channels, the beam intensity is:

$$I_1 = I_0 \times \rho_1 \times \rho_2 = I_0 \times \tau_1,$$

for the second:

$$I_2 = I_0 \times \tau_3 = I_0 \times \tau_2,$$

where I_0 - is the intensity at the input of each of the channels; ρ_i - are the reflection coefficients of the mirrors used in the scheme; τ_3 - is the transmittance of the semitransparent mirror.

It is known that, for the case when the intensities of the interfering beams at the input are equal, the flux distribution is represented in the form [4]:

$$\Phi = 2\Phi_0\left\{1 + \exp\left[-\pi\Delta v\right]\exp\left[-\frac{\alpha_1^2 + \alpha_2^2}{\Theta^2}\right]\cos(2\pi v\tau + k_0 D\alpha)\right\}, \quad (3)$$

where $\Phi_0 = \frac{2\Phi_n}{\pi \cdot w_0^2}$; w_0 - is the size of the beam waist section; Θ - beam divergence angle; Δv - is the width of the spectral line of laser radiation; v - is the frequency of the generated oscillation; $\alpha_i = \frac{r_i}{z}$ -angular coordinates of the interacting points of the wave front relative to its center; $k_0=2\pi/\lambda$ - is the wave number; α - is the angle of rotation of the receiving unit in the plane of laser radiation propagation.

In the dynamic mode, expression (3) has the form

$$\Phi = \Phi_0 \left\{ \tau_1 \int_{x_1}^{x_2}\int_{a_1}^{a_2} \exp\left[-2\frac{x^2+y^2}{w^2} \right] dxdy + \tau_2 \int_{-x_1}^{-x^2}\int_{a_1}^{a_2} \exp\left[-2\frac{x^2+y^2}{w^2} \right] dxdy + \right.$$

$$\left. + 2\sqrt{\tau_1 \int_{x_1}^{x_2}\int_{a_1}^{a_2} \exp\left[-2\frac{x^2+y^2}{w^2} \right] dxdy \times \tau_2 \int_{-x_1}^{-x_2}\int_{a_1}^{a_2} \exp\left[-2\frac{x^2+y^2}{w^2} \right] dxdy} \right\} \gamma_{12}(\rho,\tau)$$

(4)

Transforming equation (4), we get:

$$\Phi = \frac{4\sqrt{2}}{\pi}\Phi_л \tau_a \tau_k \left(\frac{U_d}{\Theta}\right)^2 \times \left[1 - \frac{1}{6}\left(\frac{U_d}{\Theta}\right)^2\right] \times \left[1 - \frac{1}{2}\left(\frac{U_d}{\Theta}\right)^2 - \frac{1}{3}\left(\frac{U_d}{\Theta}\right)^2\right] \times$$

$$\times \left\{1 + \exp\left[-\frac{1}{2}\left(\frac{U_d}{\Theta}\right)^2\right] \exp\left[-2\left(\frac{\beta}{\Theta}\right)^2\right] \cos k_0 \left[x\phi_0 + D\beta\right]\right\},$$

where U_d - is the aperture angle of the receiving channel, τ_a - is the transmittance of the atmosphere.

It is known that the limiting angular sensitivity of an interferometer is determined by the expression

$$\Delta\varphi_{prel} = \frac{\pi \cdot m \cdot \Phi_{thresh}}{16\sqrt{2} \cdot \Phi_л \cdot \tau_a \left(\frac{U_d}{\Theta}\right)^2 \left[1 - \frac{1}{2}\left(\frac{U_d}{\Theta}\right)^2\right] \left[1 - \frac{1}{2}\left(\frac{U_d}{\Theta}\right)^2 - \frac{1}{12}\left(\frac{U_d}{\Theta}\right)^2\right]} \times$$

$$\times \frac{1}{\tau_k} \exp\left[-\frac{1}{2}\left(\frac{U_d}{\Theta}\right)^2\right] \exp\left[-2\frac{\beta^2}{\Theta^2}\right] \frac{\beta^2}{\Theta^2} \sin k_0 \left[x(\varphi_0 + 2\beta)D\beta\right](D + 2x)k_0,$$

where m - is the signal-to-noise ratio, Φ_{thresh} - is the threshold sensitivity of the photodetector.

RESULT AND DISCUSSION:

By optimizing the maximum angular sensitivity due to the correct selection of the interferometer parameters, it can be shown that

$$\Delta\varphi_{prel} = \frac{1000 \cdot m \cdot \Phi_{thresh}}{\Phi_л \cdot \tau_a \cdot \tau_k \cdot k_0 \frac{w}{\Theta} \sin k_o \left[x(\varphi_0 + 2\beta) + D\beta\right]}.$$

(5)

It was also proved that for two-mirror interferometers, taking into account (5), the limiting sensitivity is

$$\Delta\varphi_{prel} = 159{,}1\frac{\Phi_{thresh}}{\Phi_л} \cdot \frac{\lambda \cdot \varphi_{\max}}{R \cdot \Delta\varphi \cdot \tau_a \cdot \tau_k}.$$

(6)

Formula (5) allows for the optimal choice of a radiation source based on the main parameters of the device and technical requirements for it.

The transition to an electrical signal can be carried out through the spectral sensitivity of the used radiation detector $U_s = S_{u\lambda} * I$, however, this approach seems to be rather complicated in implementation, creates significant difficulties in processing and does not allow taking into account all signal distortions.

CONCLUSION:

A mathematical analysis of the parameters of the intensity of illumination in the interference region of dynamic objects, which make it possible to increase the accuracy of measuring small angular displacements, and methods for determining the small angular displacement of the radiation source when the interference region and the width of the interference fringe are displaced.

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