A technique for measuring local particle concentrations in dispersed flows is considered. Operation of the optoelectronic apparatus used is analyzed for "single particle" and "multiparticle" cases.

The simple method of dispersed particle concentration measurement proposed in [1] has been employed successfully in the study of two-phase flows of various types.

Below we will present a detailed description and analysis of this method with consideration of the following major assumptions: \( r \), the optical thickness of the dispersed medium studied, satisfies "single" scattering conditions; the particle diffraction parameter \( \rho_s \gg 1 \); the particle radius \( r_s \) satisfies the condition \( r_s < r_f \) (here and below the index \( s \) indicates parameters of the dispersed particles).

One beam of a differential circuit laser [2] will be used with wave vector \( k_{02} \) and power \( P_0 \), focused on the portion of flow to be studied. The light scattered by the particles is collected by an optical receiving system located in the plane \( xy \) at an angle \( \theta \) to the direction \( \overrightarrow{k_{02}} \) (Fig. 1a). The dimensions of the region to be considered depend on the radius of the laser beam \( r_f \) in the constricting region and the parameters of the receiver optical system, being defined by the following expressions:

\[
\Delta x = 2 r_f \cos^{-1} \theta; \quad \Delta y = a \sin^{-1} \beta \left[ \frac{d_1}{l_1} - 1 \right]; \quad \Delta z = 2 r_f.
\]  

(1)

The radius \( r_f \) at the level \( \exp (-1) \) and the divergence angle \( \theta_0 \) defining the degree of parallelism within the limits of the region \( \Delta y \), are found from the expressions [3]:

\[
r_f = \left[ \frac{1}{k_0} \left[ \left( 1 - \frac{R_e}{f_0} \right)^2 + \left( \frac{R_0}{2f_0} \right)^2 \right] \right]^{1/2};
\]

\[
\theta = \left[ \frac{2 \lambda_0}{\pi R_e} \left( 1 - \frac{d_s}{f_0} \right)^2 + \left( \frac{R_0}{2f_0} \right)^2 \right]^{1/2}.
\]

(2)

The laser beam electric field complex amplitude distribution \( E(R, t) \) in the measurement region for the case of a Gaussian beam is given by

\[
E(R, t) = \left( \frac{P_0}{\pi r_f^2} \right)^{1/2} \exp \left[ -\frac{x^2 + z^2}{2 r_f^2} \right].
\]

(3)

The light intensity, or mean energy density in the beam section in the measurement volume, is found from

\[
I(x, z) = \frac{1}{2} \sqrt{\frac{\mu}{\varepsilon}} \left| E(R, t) E^*(R, t) \right| = \frac{P_0}{\pi r_f^2} \exp \left( -\frac{x^2 + z^2}{2 r_f^2} \right).
\]

(4)

Assuming that \( r_s \ll r_f \) the light flux \( P_s(\beta) \) scattered by a fixed particle with coordinates \( x_K z_K \) into solid angle \( \Delta \Omega \) in the direction \( \overrightarrow{k_{02}} \) at an angle \( \beta \) to \( \overrightarrow{k_{02}} \) is equal to

\[
P_s(\beta) = I(x_K z_K) \int_{\Delta \Omega} d\sigma_n(p, \beta) = I(x_K z_K) S_a(p, \beta, \Delta \Omega).
\]

(5)
Fig. 1. Experimental geometry: a) overview; 1, 3, receiver objectives with aperture diaphragms for scattered (1) and direct (3) beams; 2, 4 point diaphragms ahead of type FEU-68 photomultipliers for first (PM-1) and second (PM-2) channels; 5, electronic signal processing circuitry for both channels. b) Diagram of direct and scattered beams.

In writing Eq. (5) it was assumed that the change in light intensity over the particle can be neglected. From Eqs. (4) and (5) there follows an expression for the "optical signal" at the photodetector input

$$P_{opt}(\beta) = \tau_0 \frac{P_0}{\pi r_i^2} \exp \left( - \frac{x_i^2 + z_i^2}{r_i^2} \right) S_n(\rho_x, \beta, \Delta \theta).$$  

Light flux (6) defines the value of the constant electrical signal at the photodetector output. Introducing the quantity \( \chi \), which characterizes the sensitivity of the receiver system, we obtain from Eq. (6) an expression for the signal at the photomultiplier output from the fixed K-th scattering particle with coordinates \( \chi_{x,y} \) in the interval \( \Delta y \):

$$I_n(\beta) = k_\beta \frac{\nu e}{h v_0} \left\{ \tau_0 \frac{P_0}{\pi r_i^2} \exp \left( - \chi^2 \frac{x_i^2 + z_i^2}{c^2} \right) S_n(\rho_x, \beta, \Delta \theta) \right\}.$$  

In analyzing dispersed flows as functions of particle concentration and size of the measurement region there exist two modes of measurement system operation: "multiparticle" and "single particle."

The "multiparticle" mode is realized under the condition \( N_s \Delta V \gg 1 \), where \( N_s \Delta V = N_s V \) is the mean statistical number of particles in the volume \( V \); \( N_s \), mean particle concentration in the measurement region. In the given situation the mean (over time) value of the photocurrent at the photomultiplier output can be calculated from the expression

$$\overline{i_1}(\beta, t) = \frac{N_s V}{\Delta V} \left\{ \sum_{h=1}^{N_{\Delta V}} I_n(\beta) \right\} = \overline{N_{AV}} \langle I_n(\beta) \rangle.$$  

In Eq. (6) \( M \) is the mathematical expectancy; a line above a quantity denotes averaging over time; the double brackets \( \langle \rangle \) denote averaging over coordinates and the set of particles. Now in Eq. (7) we take \( x_K = U_0(t-t_K) \) and perform the averaging operations of Eq. (8) for \( i_1(\beta, t) \), and we obtain

$$\overline{i_1}(\beta, t) = \overline{N_{AV}} \langle I_0 \rangle \left\{ k_\beta \frac{\nu e}{h v_0} \tau_0 \Phi(2 \chi) \right\} \lesssim(\rho_x, \beta, \Delta \theta).$$  

The "single particle" operating mode occurs at \( N_s \Delta V \leq 1 \). Now the photocurrent \( i_2(\beta, t) \) is a sequence of pulses with random amplitude and phase:

$$i_2(\beta, t) = \sum_{k=1}^{n} i_{\text{in}}(t - t_k),$$  

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