Quantum Electronics **40** (6) 551 – 555 (2010)

PACS numbers: 42.62.Fi; 87.63.dk
DOI: 10.1070/QE2010v040n06ABEH014296

Laser Doppler visualisation of the fields of three-dimensional velocity vectors with the help of a minimal number of CCD cameras

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Abstract. **We discuss the possibility of laser Doppler visualisation and measurement of the field of three-dimensional velocity vectors by suppressing the multiparticle scattering influence on the measurement results, when using one CCD camera. The coordinate measuring basis is formed due to switching of the directions and the frequency of spatially combined laser sheets, the frequency being synchronised with the CCD-camera operation. The field of the velocity vectors without the contribution from the multiparticle scattering is produced from the linear combinations of normalised laser sheet images detected with a CCD camera in a frequency-demodulated scattered light. The method can find applications not only in laser diagnostics of gas and condensed media but also in the Doppler spectroscopy of light fields scattered by multiparticle dynamic structures.**

Keywords: *laser Doppler visualisation of the velocity field, Doppler global velocimetry, planar Doppler velocimetry, laser Doppler spectroscopy.*

1. Introduction

Laser Doppler visualisation and measurement of the velocity fields, which was historically termed Doppler global velocimetry (DGV) and is recently known as planar Doppler velocimetry (PDV), is being actively developed. It finds wide application in experimental hydro- and gas-dynamics when optically diagnosing the flows [1 – 10]. The DGV method is based on obtaining laser sheet images in a frequency-demodulated light scattered by the flow particles. The normalised image of the studied flow cross section unambiguously shows the Doppler frequency shift distributions and, hence, the velocity projections of the particles in the direction specified by the difference between the wave vectors of laser radiation and scattered light. Normalisation involves finding the ratio of the signal and reference images, which can be obtained by using separate [3 – 5] and single CCD cameras [8 – 10]. The use of one camera is more preferable because the number of detection channels is reduced and the problems of the signal and reference CCD camera parameter matching are eliminated.

In visualising the fields of 2D and 3D velocity vectors by the conventional DGV methods, the number of detection channels containing CCD cameras and the frequency – intensity converter usually corresponds to the dimensionality of the coordinate measuring basis [4, 5]. The three-dimensional measurements of the velocity field with the formation of the coordinate measuring basis due to the switching differently directed laser sheets and with the use of one image detection channel are described in papers [6, 7]. The authors of paper [9] considered the PDV method making it possible to measure the field of the 3D velocity vectors with the help of one CCD camera synchronised with the frequency modulation of the laser sheet and simultaneous detection of four separate images of the laser sheet in light beams scattered in four different directions. Combinations of these directions with the wave vector direction of the laser sheet form the coordinate measuring 3D basis. This system employs four multifibre waveguide channels producing frequency-demodulated images on the CCD-camera matrix. This configuration is a slightly simpler than that of the measuring system with four CCD cameras.

The commonly encountered problem in using the DGB (PDV) technique is the increase in the effect of multiparticle scattering on the measurements of the velocity field with increasing the concentration of scattering particles in the flow under study. Paper [10] shows the possibility of eliminating the multiparticle scattering effect by employing the DGV methods with separate signal and reference cameras as well as with one CCD camera in the detection channel of the laser sheet images in a frequency-demodulated light. However, application of this method requires laser sheet images to be obtained at two angles while measuring the field of the velocity vector projections in one specified direction. Therefore, to measure the field of the 3D velocity vectors by the method described in [10], it is necessary to use at least six CCD cameras, two in each direction of the selected coordinate measuring basis, which, surely, complicates the measuring system and significantly limits its application. Minimisation of the number of optical channels in visualising and measuring the field of the 3D velocity vectors by suppressing the multiparticle scattering effect is one of the main problems of modern DGV technologies. Therefore, in this paper we discuss the ways to overcome this problem.

2. Laser Doppler visualisation of the field of 3D velocity vectors with the help of one CCD camera

To solve this problem, the flow cross section under study is illuminated by spatially combined and successively time-commutated laser sheets $P_1(\boldsymbol{k}_1, \tilde{\boldsymbol{k}}_1)$ and $P_2(\boldsymbol{k}_2, \tilde{\boldsymbol{k}}_2)$ whose wave vectors $\boldsymbol{k}_1$ and $\boldsymbol{k}_2$ ($\tilde{\boldsymbol{k}}_1$ and $\tilde{\boldsymbol{k}}_2$) are oriented mutually orthogonal, as is shown in Fig. 1. The laser sheet $P_1(\boldsymbol{k}_1, \tilde{\boldsymbol{k}}_1)$ is formed by

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Received 15 February 2010; revision received 6 April 2010
Kvantovaya Elektronika **40** (6) 551 – 555 (2010)
Translated by I.A. Ulitkin

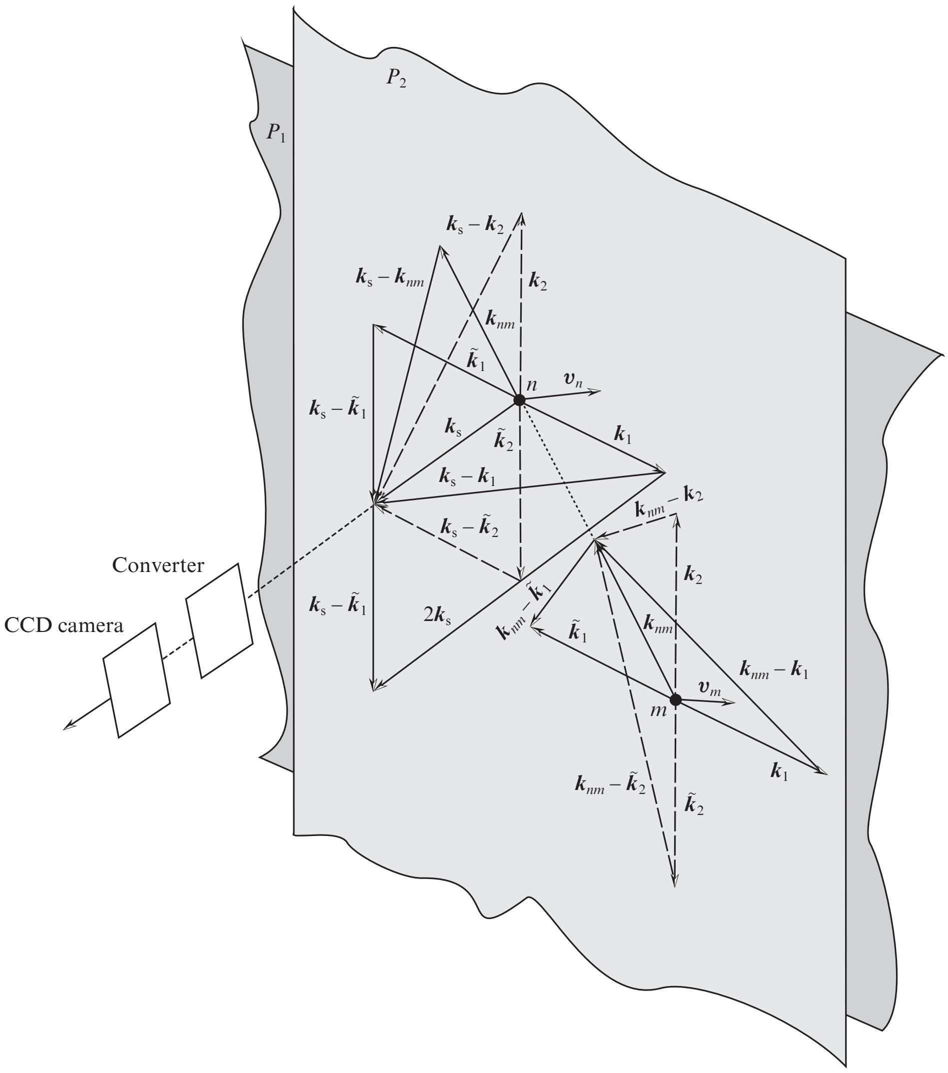

Figure 1. Configuration of light beams in the space of the wave vectors, which illustrates the measurement of the field of the 3D velocity vectors with the help of one detection channel.

two oppositely directed and successively time-commutated frequency-modulated laser beams with the wave vectors $\boldsymbol{k}_1$ and $\tilde{\boldsymbol{k}}_1$, where $\tilde{\boldsymbol{k}}_1 = -\boldsymbol{k}_1$, $|\tilde{\boldsymbol{k}}_1| = |\boldsymbol{k}_1| = k$. The laser sheet $P_2(\boldsymbol{k}_2, \tilde{\boldsymbol{k}}_2)$ is formed by oppositely directed and successively time commutated laser beams with the wave vectors $\boldsymbol{k}_2$ and $\tilde{\boldsymbol{k}}_2$, where $\tilde{\boldsymbol{k}}_2 = -\boldsymbol{k}_2$, $|\tilde{\boldsymbol{k}}_2| = |\boldsymbol{k}_2| = k$. Radiation in the laser sheet is scattered from the particles in the flow. The laser sheet image is detected with a CCD camera in the frequency-demodulated light. The CCD-camera operation is synchronised with the commutation of the laser beams successively forming the laser sheets. The scattered light is frequency demodulated by the frequency–intensity converter based, for example, on a molecular absorbing cell or optical resonator [9, 10].

Let the light sheets P_1 and P_2 be formed in the following sequence:

$$P(\omega_0, t) = \sum_{q=0}^{N} \{P_1(\omega_0, \boldsymbol{k}_1)\{\sigma(t - q\tau) - \sigma[t - (q+1)\tau]\}$$

$$+ P_1(\omega_0, \tilde{\boldsymbol{k}}_1)\{\sigma[t - (q+1)\tau] - \sigma[t - (q+2)\tau]\} +$$

$$+ P_2(\omega_0, \boldsymbol{k}_2)\{\sigma[t - (q+2)\tau] - \sigma[t - (q+3)\tau]\}$$

$$+ P_2(\omega_0, \tilde{\boldsymbol{k}}_2)\{\sigma[t - (q+3)\tau] - \sigma[t - (q+4)\tau]\}\}, \qquad (1)$$

where ω_0 is the fundamental laser frequency; $\sigma(t)$ is the Heaviside function (switching on function); τ is the time interval during which the flow cross section is illuminated by the laser sheet of the given configuration; N is the number of switching cycles. The interval τ is determined by the switching frequency of the laser sheets, $\tilde{\omega} = 2\pi/\tau$. The fields of the velocity vector projections in the coordinate 3D basis are simultaneously measured in the spectral band limited by the Nyquist frequency.

Commutation of the laser sheets is synchronised with the operation of the CCD camera detecting the cross section images of the studied flow in the frequency-demodulated scattered light. The light scattered in the laser sheet is frequency demodulated by the frequency–intensity converter with a controlled transfer function according to the technology described in [10]. This technique is based on the frequency modulation of the laser shit by the law

$$\tilde{P}(t) = [1 + \mathrm{sgn}(\sin\tilde{\omega}t)]P[(\omega_0 + \Omega)t]$$

$$+ [1 - \mathrm{sgn}(\sin\tilde{\omega}t)]P[(\omega_0 - \Omega)t], \quad (2)$$

where $P[(\omega_0 \pm \Omega)t]$ is determined by expression (1). The frequencies $\omega_0 \pm \Omega$ correspond to the working points on the slopes of the transfer functions, which play the role of discrimination curves [9, 10]. The laser radiation frequency ω_0 corresponds to the central frequency of the transfer function of the frequency–intensity converter. For each realisation of the laser sheet with the wave vectors $\boldsymbol{k}_1$, $\tilde{\boldsymbol{k}}_1$, $\boldsymbol{k}_2$, $\tilde{\boldsymbol{k}}_2$, the CCD camera successively detects a couple of images of the nth particle in the frequency-demodulated light in the vicinity of the frequencies $\omega_0 \pm \Omega$. By using expression (2), we will write expressions for the complex amplitudes E_n of light scattered by the nth particle from the successively commutated laser sheets. For the laser sheets

$$[1 + \mathrm{sgn}(\sin\tilde{\omega}t)]P_1(\omega_0 + \Omega, \boldsymbol{k}_1) + [1 - \mathrm{sgn}(\sin\tilde{\omega}t)]P_1(\omega_0 - \Omega, \boldsymbol{k}_1)$$

and

$$[1 + \mathrm{sgn}(\sin\tilde{\omega}t)]P_1(\omega_0 + \Omega, \tilde{\boldsymbol{k}}_1) + [1 - \mathrm{sgn}(\sin\tilde{\omega}t)]P_1(\omega_0 - \Omega, \tilde{\boldsymbol{k}}_1)$$

we have

$$E_n(\Omega, \boldsymbol{k}_\mathrm{s}, \boldsymbol{k}_1) = AS_n \exp\{\mathrm{i}[\omega_0 + \Omega + \boldsymbol{v}_n(\boldsymbol{k}_\mathrm{s} - \boldsymbol{k}_1)]t + \mathrm{i}\varphi_n\}$$

$$+ A\sum_m S_{nm} \exp\{\mathrm{i}[\omega_0 + \Omega + \boldsymbol{v}_m(\boldsymbol{k}_{nm} - \boldsymbol{k}_1)$$

$$+ \boldsymbol{v}_n(\boldsymbol{k}_\mathrm{s} - \boldsymbol{k}_{nm})]t + \mathrm{i}\varphi_{nm}\}, \quad (3)$$

$$E_n(-\Omega, \boldsymbol{k}_\mathrm{s}, \boldsymbol{k}_1) = AS_n \exp\{\mathrm{i}[\omega_0 - \Omega + \boldsymbol{v}_n(\boldsymbol{k}_\mathrm{s} - \boldsymbol{k}_1)]t + \mathrm{i}\varphi_n\}$$

$$+ A\sum_m S_{nm} \exp\{\mathrm{i}[\omega_0 - \Omega + \boldsymbol{v}_m(\boldsymbol{k}_{nm} - \boldsymbol{k}_1)$$

$$+ \boldsymbol{v}_n(\boldsymbol{k}_\mathrm{s} - \boldsymbol{k}_{nm})]t + \mathrm{i}\varphi_{nm}\}, \quad (4)$$

$$E_n(\Omega, \boldsymbol{k}_\mathrm{s}, \tilde{\boldsymbol{k}}_1) = AS_n \exp\{\mathrm{i}[\omega_0 + \Omega + \boldsymbol{v}_n(\boldsymbol{k}_\mathrm{s} + \boldsymbol{k}_1)]t + \mathrm{i}\tilde{\varphi}_n\}$$

$$+ A\sum_m S_{nm} \exp\{\mathrm{i}[\omega_0 + \Omega + \boldsymbol{v}_m(\boldsymbol{k}_{nm} + \boldsymbol{k}_1)$$

$$+ \boldsymbol{v}_n(\boldsymbol{k}_\mathrm{s} - \boldsymbol{k}_{nm})]t + \mathrm{i}\tilde{\varphi}_{nm}\}, \quad (5)$$

$$E_n(-\Omega, \boldsymbol{k}_\mathrm{s}, \tilde{\boldsymbol{k}}_1) = AS_n \exp\{\mathrm{i}[\omega_0 - \Omega + \boldsymbol{v}_n(\boldsymbol{k}_\mathrm{s} + \boldsymbol{k}_1)]t + \mathrm{i}\tilde{\varphi}_n\}$$

$$+ A\sum_m S_{nm} \exp\{\mathrm{i}[\omega_0 - \Omega + \boldsymbol{v}_m(\boldsymbol{k}_{nm} + \boldsymbol{k}_1)$$

$$+ \boldsymbol{v}_n(\boldsymbol{k}_\mathrm{s} - \boldsymbol{k}_{nm})]t + \mathrm{i}\tilde{\varphi}_{nm}\}, \quad (6)$$

where A is the amplitude of the incident light field with the wave vector $\boldsymbol{k}$; S_n is the nth particle scattering function in the direction of the wave vector $\boldsymbol{k}_s$; S_{nm} is the nth particle scattering indicatrix in the direction of the wave vector $\boldsymbol{k}_s$ for light incident on the nth particle from the mth particle; $\boldsymbol{v}_n$ and $\boldsymbol{v}_m$ are the velocities of the nth and mth particles; φ_n and $\tilde{\varphi}_n$ are the light wave phases determined by the position of the nth particle in the corresponding laser sheet; $\boldsymbol{k}_{nm} = \boldsymbol{k}_n - \boldsymbol{k}_m$ is the wave vector of the light wave scattered by the mth particle in the direction of the nth particle; $\boldsymbol{v}_m(\boldsymbol{k}_{nm} - \boldsymbol{k}_1)$ is the Doppler frequency shift of the light wave scattered by the mth particle in the direction of the nth particle; $\boldsymbol{v}_n(\boldsymbol{k}_\mathrm{s} - \boldsymbol{k}_{nm})$ is the Doppler frequency shift of the light wave with the wave vector $\boldsymbol{k}_\mathrm{s}$, scattered by the nth particle and incident on this particle from the side of the mth particle; φ_{nm} and $\tilde{\varphi}_{nm}$ are the light field phases determined by the position of the nth and mth particles in the laser sheet.

The light field scattered by the nth particle propagates in the $\boldsymbol{k}_\mathrm{s}$ direction, is transformed by the frequency–intensity converter and detected with the CCD camera. The expression for the intensity of the i_n field forming the image of the nth particle in the frequency-demodulated light scattered in the $\boldsymbol{k}_\mathrm{s}$ direction is obtained from (3)–(6):

$$i_n(\Omega, \boldsymbol{k}_\mathrm{s}, \boldsymbol{k}_1) = \xi A^2 \Big\{\Big(S_n^2 + \sum_m S_{nm}^2\Big)[\Omega + \boldsymbol{v}_n(\boldsymbol{k}_\mathrm{s} - \boldsymbol{k}_1)]$$

$$+ \sum_m S_{nm}^2(\boldsymbol{v}_{nm}\boldsymbol{k}_1 + \boldsymbol{v}_{mn}\boldsymbol{k}_{nm})\Big\}, \quad (7)$$

$$i_n(-\Omega, \boldsymbol{k}_\mathrm{s}, \boldsymbol{k}_1) = \xi A^2 \Big\{\Big(S_n^2 + \sum_m S_{nm}^2\Big)[\Omega - \boldsymbol{v}_n(\boldsymbol{k}_\mathrm{s} - \boldsymbol{k}_1)]$$

$$- \sum_m S_{nm}^2(\boldsymbol{v}_{nm}\boldsymbol{k}_1 + \boldsymbol{v}_{mn}\boldsymbol{k}_{nm})\Big\}, \quad (8)$$

$$i_n(\Omega, \boldsymbol{k}_\mathrm{s}, \tilde{\boldsymbol{k}}_1) = \xi A^2 \Big\{\Big(S_n^2 + \sum_m S_{nm}^2\Big)[\Omega + \boldsymbol{v}_n(\boldsymbol{k}_\mathrm{s} + \boldsymbol{k}_1)]$$

$$+ \sum_m S_{nm}^2(\boldsymbol{v}_{mn}\boldsymbol{k}_{nm} - \boldsymbol{v}_{nm}\boldsymbol{k}_1)\Big\}, \quad (9)$$

$$i_n(-\Omega, \boldsymbol{k}_\mathrm{s}, \tilde{\boldsymbol{k}}_1) = \xi A^2 \Big\{\Big(S_n^2 + \sum_m S_{nm}^2\Big)[\Omega - \boldsymbol{v}_n(\boldsymbol{k}_\mathrm{s} + \boldsymbol{k}_1)]$$

$$- \sum_m S_{nm}^2(\boldsymbol{v}_{mn}\boldsymbol{k}_{nm} - \boldsymbol{v}_{mn}\boldsymbol{k}_1)\Big\}. \quad (10)$$

Here, ξ is the frequency–intensity conversion coefficient for the converter; $\boldsymbol{v}_{mn} = \boldsymbol{v}_m - \boldsymbol{v}_n$. These images are stored and subjected to simple linear transformations. In summing (7) and (8) or (9) and (10), we obtain

$$i_n(\Omega, \boldsymbol{k}_\mathrm{s}, \boldsymbol{k}_1) + i_n(-\Omega, \boldsymbol{k}_\mathrm{s}, \boldsymbol{k}_1) = i_n(\Omega, \boldsymbol{k}_\mathrm{s}, \tilde{\boldsymbol{k}}_1) + i_n(-\Omega, \boldsymbol{k}_\mathrm{s}, \tilde{\boldsymbol{k}}_1)$$

$$= 2\xi A^2 \Big(S_n^2 + \sum_m S_{nm}^2\Big)\Omega. \quad (11)$$

Let us find the sum of images (7) and (9):

$$i_n(\Omega, \boldsymbol{k}_\mathrm{s}, \boldsymbol{k}_1) + i_n(\Omega, \boldsymbol{k}_\mathrm{s}, \tilde{\boldsymbol{k}}_1)$$

$$= 2\xi A^2 \Big[\Big(S_n^2 + \sum_m S_{nm}^2\Big)(\Omega + \boldsymbol{v}_n\boldsymbol{k}_\mathrm{s}) + \sum_m S_{nm}^2 \boldsymbol{v}_{mn}\boldsymbol{k}_{nm}\Big]. \quad (12)$$

Summation of images (8) and (9) yields:

$$i_n(-\Omega, \boldsymbol{k}_s, \boldsymbol{k}_1) + i_n(\Omega, \boldsymbol{k}_s, \tilde{\boldsymbol{k}}_1)$$
$$= 2\xi A^2\left[\left(S_n^2 + \sum_m S_{nm}^2\right)(\Omega + \boldsymbol{v}_n\boldsymbol{k}_1) - \sum_m S_{nm}^2 \boldsymbol{v}_{mn}\boldsymbol{k}_1\right]. \quad (13)$$

Dividing (12) and (13) by (11), we obtain

$$\Omega i_n(\boldsymbol{k}_s) = \frac{i_n(\Omega, \boldsymbol{k}_s, \boldsymbol{k}_1) + i_n(\Omega, \boldsymbol{k}_s, \tilde{\boldsymbol{k}}_1)}{i_n(\Omega, \boldsymbol{k}_s, \boldsymbol{k}_1) + i_n(-\Omega, \boldsymbol{k}_s, \boldsymbol{k}_1)}$$
$$= \Omega + \boldsymbol{v}_n\boldsymbol{k}_s + Q(\boldsymbol{v}_{mn}\boldsymbol{k}_{nm}), \quad (14)$$

$$\Omega i_n(\boldsymbol{k}_1) = \frac{i_n(-\Omega, \boldsymbol{k}_s, \boldsymbol{k}_1) + i_n(\Omega, \boldsymbol{k}_s, \tilde{\boldsymbol{k}}_1)}{i_n(\Omega, \boldsymbol{k}_s, \boldsymbol{k}_1) + i_n(-\Omega, \boldsymbol{k}_s, \boldsymbol{k}_1)}$$
$$= \Omega + \boldsymbol{v}_n\boldsymbol{k}_1 - Q(\boldsymbol{v}_{mn}\boldsymbol{k}_1), \quad (15)$$

where

$$Q(\boldsymbol{v}_{mn}\boldsymbol{k}_{nm}) = \frac{\sum_m S_{nm}^2 \boldsymbol{v}_{mn}\boldsymbol{k}_{nm}}{S_n^2 + \sum_m S_{nm}^2}, \quad (16)$$

$$Q(\boldsymbol{v}_{mn}\boldsymbol{k}_1) = \frac{\sum_m S_{nm}^2 \boldsymbol{v}_{mn}\boldsymbol{k}_1}{S_n^2 + \sum_m S_{nm}^2} \quad (17)$$

are the contributions of the multiparticle scattering to the measurement results.

The directions of the wave vectors $\boldsymbol{k}_1$ and $\boldsymbol{k}_s$ specify the coordinate 2D basis xz in which the field of the 2D velocity vectors (14) and (15) is measured. The direction of the wave vector $\boldsymbol{k}_2$ of the light beam forming the laser sheet $P_2(\boldsymbol{k}_2)$ determines the third axis of the coordinate measuring 3D basis xyz.

In analogy with (15), we have

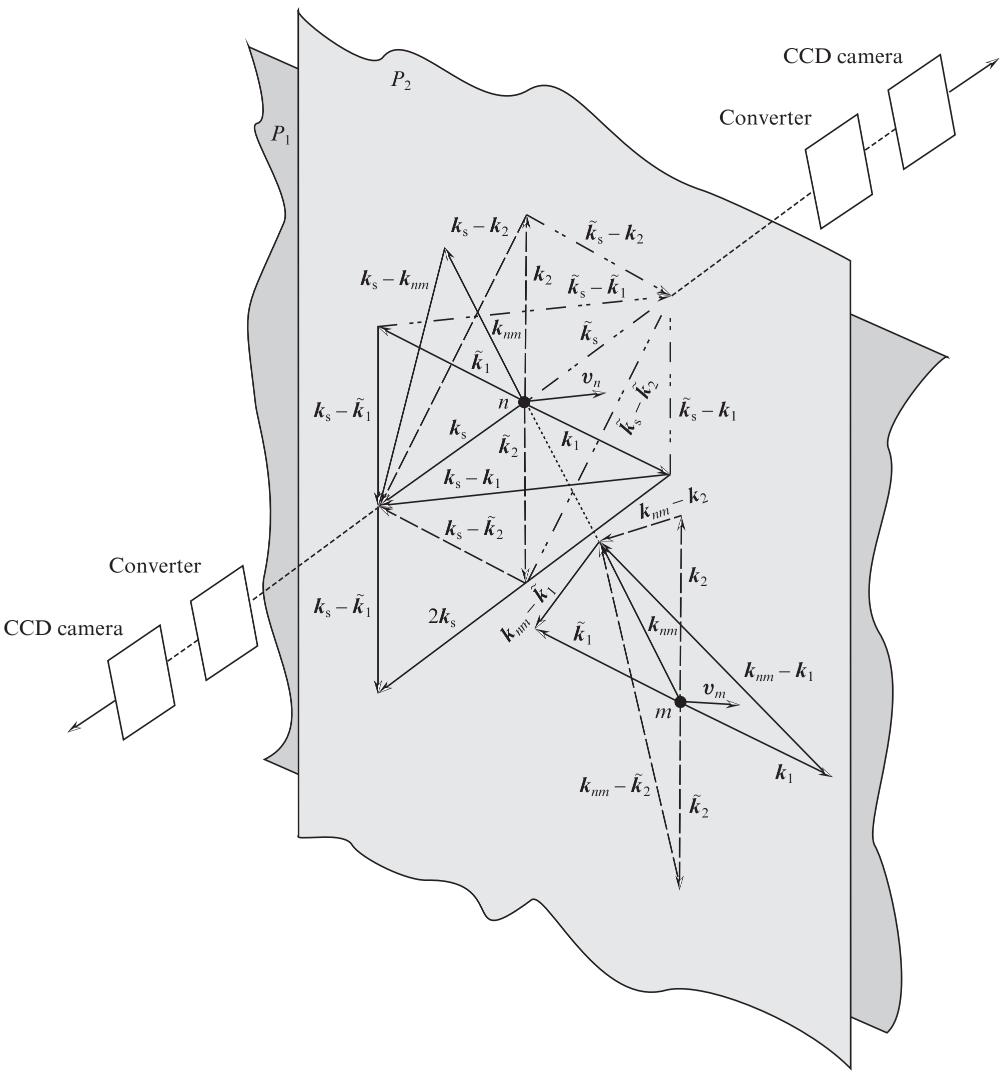

Figure 2. Configuration of light beams in the space of the wave vectors, which illustrates the measurement of the field of the 3D velocity vectors with the help of two detection channels.

$$\Omega i_n(\boldsymbol{k}_2) = \frac{i_n(-\Omega,\boldsymbol{k}_s,\boldsymbol{k}_2) + i_n(\Omega,\boldsymbol{k}_s,\tilde{\boldsymbol{k}}_2)}{i_n(\Omega,\boldsymbol{k}_s,\boldsymbol{k}_2) + i_n(-\Omega,\boldsymbol{k}_s,\boldsymbol{k}_2)}$$

$$= \Omega + \boldsymbol{v}_n\boldsymbol{k}_2 - Q(\boldsymbol{v}_{mn}\boldsymbol{k}_2), \quad (18)$$

where

$$Q(\boldsymbol{v}_{mn}\boldsymbol{k}_2) = \frac{\sum_m S_{nm}^2 \boldsymbol{v}_{mn}\boldsymbol{k}_2}{S_n^2 + \sum_m S_{nm}^2} \quad (19)$$

is the contribution of multiparticle scattering to the measurement results of the field of the velocity projections in the $\boldsymbol{k}_2$ direction. It follows from (16), (17), and (19), that the influence of multiparticle scattering becomes negligibly small in the non-gradient flow ($\boldsymbol{v}_{\rm mn} = 0$). In gradient and turbulent flows, $Q(\boldsymbol{v}_{mn}\boldsymbol{k}_1)$ and $Q(\boldsymbol{v}_{mn}\boldsymbol{k}_2)$ are negligibly small when averaging over the ensemble of scattering particles because the sums $\sum_m S_{nm}^2 \boldsymbol{v}_{mn}\boldsymbol{k}_1$ and $\sum_m S_{nm}^2 \boldsymbol{v}_{mn}\boldsymbol{k}_2$ tend to zero due to the presence of sign alternating terms in them. The contribution of the multiparticle scattering $Q(\boldsymbol{v}_{mn}\boldsymbol{k}_{nm})$ for the field components of the velocities in the $\boldsymbol{k}_s$ direction in the case of averaging does not disappear because the terms in the sum $\sum_m S_{nm}^2 \boldsymbol{v}_{mn}\boldsymbol{k}_{nm}$ are not sign alternating. If it is necessary to suppress $Q(\boldsymbol{v}_{mn}\boldsymbol{k}_{nm})$, one can use the method described in [10]. To this end, the second detection channel of the field image is introduced in the frequency-demodulated light scattered in the $\tilde{\boldsymbol{k}}_s$ direction, opposite to the direction of the $\boldsymbol{k}_s$ vector: $\tilde{\boldsymbol{k}}_s = -\boldsymbol{k}_s$ (Fig. 2). Then, for the normalised image of the nth particle in the frequency-demodulated light, we can write an expression similar to (14), where $\boldsymbol{k}_s$ should be replaced by $-\boldsymbol{k}_s$:

$$\Omega i_n(\boldsymbol{k}_s) = \frac{i_n(\Omega,-\boldsymbol{k}_s,\boldsymbol{k}_1) + i_n(\Omega,-\boldsymbol{k}_s,\tilde{\boldsymbol{k}}_1)}{i_n(\Omega,-\boldsymbol{k}_s,\boldsymbol{k}_1) + i_n(-\Omega,-\boldsymbol{k}_s,\boldsymbol{k}_1)}$$

$$= \Omega - \boldsymbol{v}_n\boldsymbol{k}_s + Q(\boldsymbol{v}_{mn}\boldsymbol{k}_{nm}). \quad (20)$$

It follows that the field of the velocity components in the $\boldsymbol{k}_s$ direction upon suppressing the multiparticle scattering effect is found as a difference of images (14) and (20):

$$\Omega[i_n(\boldsymbol{k}_s) - i_n(-\boldsymbol{k}_s)] = 2\boldsymbol{v}_n\boldsymbol{k}_s.$$

The described measurement of the field of 3D velocities with the help of one CCD camera, apart from the possibility of suppressing the multiparticle scattering effect, provides (compared, for example, to [9]) a higher resolution due to the use of the entire photomatrix of the camera detecting the image of the flow cross section under study. In addition, energy losses caused by the use of waveguide channels forming the image are absent and the structure of the optical measuring system is simplified. This technique can useful in laser Doppler spectroscopy of the light fields scattered by multiparticle dynamic systems.

3. Conclusions

We have shown the possibility of laser Doppler visualisation and measurement of the field of 3D velocity vectors with the help of a minimal number of CCD cameras and with the suppression of the multiparticle scattering effect by the DVG(PDV) methods. In this case, the flow cross section under study is illuminated by spatially combined and successively commutated laser sheets whose wave vectors are oriented mutually orthogonal. Each of these sheets is produced by oppositely directed laser beams, that are successively commutated and frequency modulated. Switching of the laser beams is synchronised with the operation of the CCD camera detecting the images of the studied flow cross section in the frequency-demodulated light. The light scattered in the laser sheet is frequency demodulated by the frequency–intensity converter with a controlled transfer function, in accordance with the technique described in [10]. The normalised fields of the velocity vector projections are obtained from the simple linear combinations of detected images in the coordinate measuring 3D basis. In this case, for the field of the 2D velocity vectors in the coordinate basis specified by the wave vectors of the laser sheets, the contribution of the multiparticle scattering to the measurement result is suppressed due to averaging over the ensemble of scattering particles. The field of the velocity projections onto the axis orthogonal to the laser sheet contains the uncompensated contribution of the multiparticle scattering.

The contribution of the multiparticle scattering for these velocity projections can be suppressed by introducing the second detection channels with a CCD camera located symmetrically to the first camera with respect to the laser sheet. The difference in the normalised images detected by the first and second CCD cameras gives the field of the velocity projections onto the direction orthogonal to the laser sheet, with the suppression of the contribution from the multiparticle scattering.

Acknowledgements. This work was supported by the Russian Foundation for Basic Research (Grant No. 10-08-00813a).

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