Diagnosis of low-speed flows by particle shadow velocimetry method

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Abstract. The method of particle shadow anemometry is one of the PIV modifications. LEDs are used as a radiation source. The application of particle shadow anemometry for diagnostics of low-speed vortex flows is considered in this article. The ability to obtain both visualization of the flow and numerical results was shown.

1. Introduction
Currently, optical methods are widely used in the experiment to measure the parameters of single-phase and two-phase flows. They do not cause disturbances in the flow and have a high temporal and spatial resolution. Low speeds measurement is an integral part of changes, for example, aerodynamic. The aerodynamic force acting on a free-flying model can be determined by measuring the acceleration of the model. If the size of the model does not allow installing the necessary devices on it, the acceleration is found by changing the speed of the model along the path.

The method of particle shadow velocimetry (PSV) is promising in the velocity measurement field, due to its simplicity and low cost relative to laser methods. In case of particle symmetry, the method does not require high-precision adjustment, which makes it faster and easier to obtain the measurement result. This method can be implemented with a single wavelength led and a black and white camera, but the time dynamic range can be increased by using multi-colour LEDs (white) and a colour camera. In this paper, the possibility of using the Scheimpflug adapter for the diagnosis of low-speed flows by particle shadow velocimetry will be considered.

2. Particle Shadow Velocimetry (PSV)
In the method particle shadow velocimetry (PSV) [1-4] LED are used as the light source, with a power is much lower than that of lasers. This technique is presented as a modification of particle image velocimetry (PIV) [5, 6]. PSV neglects the wave nature of light and takes as a basis only the approximation of geometric optics.

Lighting directed in a straight line to the camera matrix is provided by an incoherent source, such as a light-emitting diode (LED). Thus, we are able to distinguish small particles with less energy and time for adjustment.

In an installation based on the PSV technique, it is possible to adjust parameters such as depth of field, field of view and working distance. Such adjustments can be made using the Scheimpflug adapter in addition to the lens.
The attractive side of this new method is the flexibility in the choice of radiation receivers. At the moment, there are no limiting conditions for the selection of the camera, and therefore during the experiment it is necessary to be guided only by the characteristics that are necessary to perform a specific task.

3. Experimental setup
Figure 1 shows an experimental setup for measuring the velocity of particles in water (2). To obtain a shadow of particles in water, dot LEDs (1) with a diverging angle of 120° of different colors (red, green, blue and white) were used as the radiation source. The shooting was carried out using a high-speed camera (4) connected directly to the computer (5). For research, a high-speed camera Fastec Hispec 1 was used with the Scheimpflug adapter [7] and 50 mm objective (3).

The program specially installed on the computer allows not only to select the necessary shooting parameters (frame rate per second, the required survey area, etc.), but also to immediately save the results in the required format and volume.

4. The results of experimental studies
The possibility of flows diagnostics using polystyrene particles with a diameter of 40 µm [8] was investigated. The measurements were carried out in water in a 5×3×1 cm glass cuvette. During the experiment, the survey area was limited to 800×600 pixels with a frame rate per second of 100. As a result of the experiment, sets of images were obtained, which were further processed using the cross-correlation method in the PIVViewDemo program of the PIVTECGmbH company. Processing was carried out with the following parameters: the size of the survey areas was 32×32 pixels with 50 percent overlap. For each case, normalization frames were obtained for the possibility of transition from a pixel to a metric coordinate system. This normalization allows you to get in the program ready-made values of flow rates.

As a result of processing of the experimental images obtained without the use of the Scheimpflug adapter, the vector fields of flow rates shown in figure 2 were obtained.
Figure 2. The results of cross-correlation processing of images obtained without the use of the Scheimpflug adapter.

Also during the experiment the Scheimpflug adapter, which allows to change the depth of field was used. An example of the resulting image and the result of processing in the program PIVView are shown in figure 3.

Figure 3. The results of cross-correlation processing of images obtained using the Scheimpflug adapter.

Image processing in both cases was carried out with the same parameters of the survey areas and overlap. The difference was only in the normalization of pixel / mm, due to the fact that when the lens was tilted due to the adapter, this ratio changed.

Based on the results of processing, the most attractive were vector velocity fields obtained by using a Scheimpflug adapter. As result of the normalization the values of velocity flow rates of order $10^{-3}$÷$10^{-4}$ m/s were obtained. An example of the obtained value is shown in figure 4.
Figure 4. Velocity flow rate values obtained by the cross-correlation method.

5. Conclusion
The vector fields and values of the flow velocity of the order of $10^{-3}$-$10^{-4}$ m/s in the process of mixing polystyrene particles at different times using cross-correlation processing are obtained. It was also shown that the use of the Scheimpflug adapter during shooting provides some advantage by changing the depth of field.

References
[1] Estevadeordal J and Goss L 2005 PIV with LED: Particle Shadow Velocimetry (PSV) Innovative Scientific Solutions (Inc., Dayton, OH)
[2] McPhail M J, Fontaine A A, Krane M H, Goss L and Crafton J 2015 Correcting for colour crosstalk and chromatic aberration in multicolor particle shadow velocimetry Measurement Science and Technology (Measurement Science and Technology, Journal of Physics)
[3] Chetelat O and Kim K C 2002 Miniature Particle Image Velocimetry System with LED In-Line illumination Measurement Science and Technology, Journal of Physics
[4] Whitaker S M, Reilly D, Bons J P et al. 2013 A Survey of Airborne Particle Impact Characteristics Using High Speed Particle Shadow Velocimetry DOI: 10.2514/6.2013-2484 Conference: 43rd AIAA Fluid Dynamics.
[5] Modern optical methods of flow investigation 2011 Ed. Rinkevichius B S (Moscow: Overlay)
[6] Raffel M, Willert C E, Wereley S T and Kompenhans J 2007 Particle Image Velocimetry / A Practical Guide / 2nd ed. (Springer)
[7] Prasad A K and Jensen K 1995 Scheimpflug stereo camera for particle image velocimetry in liquid flows Applied Optics
[8] Kolesnikov S Yu and Skornyakova N M 2018 Comparison of different types of tracers in the particle image velocimetry Trudy MAI (Moscow: MAI)