The study of vortexes based on the multi colored particle image velocimetry technique

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Abstract. The paper is concerned with a prospective method of qualitative and qualitative diagnostic technique – multi colored particle image velocimetry. The method proposed relies on illuminating of the studied flow by three laser planes with different wavelengths. The advantages of applying the technique in practice to investigate various flows have described. An efficiency verification of multi colored particle image velocimetry method to study vortex structures has been conducted. An experimental setup has assembled and an algorithm of the recorded images processing procedure has been developed. To assess the quality of MPIV measurements the experimental images have been compared with the computer model.

1. Introduction
Spatial velocity distribution is the main parameter that allows determining flow behavior in a gas or liquid media. The existing techniques for velocity flow measurements, based on the applying of laser light, belong to the remote, non-invasive methods allowing registering the instantaneous velocity fields in the measurement plane. Various remote sensing airs flows devices in the surface layer of the atmosphere to determine the direction and speed of the wind at the time of emergency toxic and radioactive substances emissions into the atmosphere, with the view to subsequently predict the consequences and infestation outbreaks are in high demand in the chemical and nuclear industry. In turn information about the full flow vector velocity field is necessary to solve a number of current problems in aerohydrodynamics. For instance, timely and accurate information on the air flow structure in the surface atmosphere layer will increase the safety of various aircrafts and reduce the percentage of accidents and other destructive disasters.

Accordingly the development of new non-invasive flow diagnostics methods, allowing measuring the velocity vector field and the subsequent three-dimensional flow structure visualization, took on particular relevance. Currently particle image velocimetry has become a widely used flow diagnostics and visualization methods in gas and liquid medium. The method allows the two components of flow velocity vectors to be measured simultaneously in a non-invasive manner [1].

The operation method principle is based on the laser light decomposition into a sheet in order to illuminate the investigated plane in the flow volume. Further, images are recorded due to digital camera and processed by a specialized program [2].
Recent advances in the PIV technique have been directed toward obtaining all three components of flow velocity vectors in a plane or in a volume simultaneously to allow wider applications of the PIV [3-6].

Existing advanced modifications of the PIV technique to study complex flow, such as stereo or tomographic PIV method in comparison with the planar PIV technique, allow obtaining the most complete information about flow structure. The main advantages of these methods are the capability to measure the flow velocity distribution and three-dimensional visualization. Nevertheless, the methods application in practice causes a number of difficulties involving the necessity of labor-intensive preparatory training and expensive equipment [7-11].

This paper discusses a new a prospective method of diagnostic and visualization flow technique – multi colored particle image velocimetry.

2. Multi colored particle image velocimetry
The multi colored particle image velocimetry (MPIV) technique mainly differs from the known modifications of PIV method. The proposed method allows fixing the vector velocity field in several planes simultaneously.

It relies on seeding flow with tiny tracer particles and fixing their position at short time intervals. The flow velocity is determined basing on the presumption that tracer particles follow the flow without introducing any disturbances into the flow. In order this is within reach if the particles have a small volume and mass in order not to fall under the gravity, but sufficient not to fly out of the flow. For MPIV measurements, the region of interest is illuminated by three RGB laser sheets, than the positions of particles are recorded by a color digital camera.

Each image recorded will have with different intensity three main colors. As a result, by applying in the program Pivview the cross correlation to the processed images pairs for each color channel, it is possible to obtain information about the flow vector velocities field distribution in three planes. On the basis of the data obtained, distributions of the vertical or horizontal projection of particle velocities over the selected cross sections of the studied flow could be constructed. Further, by constructing in the region of the vertical and horizontal projection particle velocity distributions for the channels of red, blue and green color for each of the sections and applying the approximation procedure of the obtained planes it is capable to visualize the studied flow three-dimensional velocity field.

Figure 1 shows the schematic of the optical-electronic setup to achieve MPIV measurements.

The measuring complex consists of a generating with different wavelengths three parallel laser sheets unit; receiving optical system involving a color CMOS matrix and a computer with specialized software. The laser unit includes a set of three semiconductor lasers of different wavelengths and an optical system. To obtain more accurate MPIV measurement results it is necessary to ensure high power density, energy characteristics uniformity and small laser sheet thickness in the region of interest as a requirement for the formation optics.

When the experimental image is decomposed into three color channels (red, green and blue), the scattered light each of the sheets shall conform to one of the colors, ideally, i.e. in the green color channel there should not be a signal from the other two colors. Herein lays the MPIV measurements technical basis.

3. Experimental setup and measurement technique
During MPIV work capacity testing, an experimental setup to investigate vortexes was developed. A vortex structure formed by a chemical stirrer model RW 16 basic in liquid pre-seeded polyamid particles 20 micrometers in diameter was the study object.

The Chroma 10 series krypton-argon laser of the Spectra-Physics company was a light source in experimental testing setup. The laser consists of a metal-ceramic discharge tube, which on a mixture of argon and krypton generates laser beam in the visible spectrum range from ultraviolet to near IR.
Figure 1. The optical-electronic setup schematic.

Figure 2 shows the experimental setup light sheets optics. The optics were included a dispersion prism, a set of four mirrors and a cylindrical lens. The need to use a spectral prism has been associated with some light source features and was to decompose the laser beam into a spectrum and select only three spectral components, which would account for the intensity maxima. As a result, the intensity peaks were observed in blue, green and red beams.

As a MPIV measurements result, scattered laser light of RGB sheets have been recorded. In turn, each image recorded was contained information about the flow velocity vector field distribution in three sheets located in 2 mm from each other. The recording on a digital camera Nikon 1J5 the video possibility with a 1200 frames/s frequency and 144×400 pixels resolution was made. Each image recorded had three primary colors with different intensity.
4. The experimental measurements processing results

The experimental results were processed as follows. At first, a video has been broken into frames. Then, over each pair of recorded images, pre-processing was carried out, which was lied in the image decomposition into three main color channels. Then the cross-correlation in the program Pivview to images pair of each color channel was applied.

In the course of the technique efficiency testing a series of experiments at chemical stirrer different modes was performed. The processing results of images pair obtained at 400 rpm stirrer speed are presented below. For each color channel there is a speed change of trace particles displacement, as shown in the figures.

![Figure 3. A vector field in the blue color channel.](image1)

![Figure 4. A vector field in the green color channel.](image2)

![Figure 5. A vector field in the red color channel.](image3)
5. The experimental results comparison with simulated ones
To assess the results quality, a chemical stirrer computer model developed in the Flow Vision software package has been considered. As shown in the figures below, in the chemical stirrer plane, a vortex in the upper right corner is formed, as well as currents in the blade plane are observed. It should be noted that the obtained results coincide qualitatively with the vector field directions of the three-dimensional model, comparing the experimental results with the simulated ones. But, nevertheless, the technique requires significant improvement to up its accuracy. The MPIV measurements in turn require the development of a lighting module and an obtaining vector fields program.

![Figure 6. A vector field in the blue color channel.](image)

![Figure 7. A vector field in the green color channel.](image)

![Figure 8. A vector field in the red color channel.](image)

6. Conclusion
The major laser measuring instruments advantages in comparison with other measuring instruments are noninvasive, remote, high temporal and spatial resolution, as well as the full automation possibility of the measuring process.

The work results indicate that the MPIV method allows obtaining a flow velocities vector field in three parallel sheets simultaneously. Therein lays the main advantage over the classic PIV technique, which gives a distribution in only one selected sheet.
A qualitative experimental data comparison with those modeled by the Flow Vision program have been showed the results validity. Further MPIV measurement improvement requires the development of program for approximating the experimental results to obtain 3D images.

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