Fluid Flows under Investigation

Particle image velocimetry and laser Doppler velocimetry for optical measurement in medical technology

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Particle image velocimetry (PIV) is a non-contact optical measurement technology for flow measurement and the visualization of complete flow fields in fluid mechanics. It is used in wind tunnels and flow channels, increasingly in medical technology, and all areas that require non-contact, non-deflecting assessment of fluid flow directions and velocities. Laser Doppler velocimetry (LDV) – or LDA (laser Doppler anemometry) – is also a non-contact technique, but in contrast to PIV, it has its main applications in the in-situ detection of fluid flow via Doppler shift. Besides research applications, the main fields of utilization include calibration of sensors and flow measurements.

**Basics of particle image velocimetry**

Particle image velocimetry takes a snapshot of a flow field within a measurement plane (Fig. 1). For this, the measured fluid is loaded with tiny particles of approx. 1 µm in size. The objective is that the particles precisely follow the flow of the fluid. Subsequently, two short coherent laser pulses illuminate the observed flow field in the measurement plane. The pulse interval is 10 µs, for example. One or more cameras detect the backscattered light from the micro particles in the flow field. The cameras are synchronized such that the images can be related to the laser pulses. These special PIV cameras are designed specifically for the task. They process the first image fast enough to be ready in time for the second image.

Due to limited laser power, lenses with low f-number are used. Therefore the depth of focus is only small. In order to span the complete measurement plane in spite of the low depth of focus,
the cameras are mounted following the Scheimpflug principle (Fig. 2).

Here, the cameras are positioned so that the planes of image, lens and focus cross along a mutual line. Thus, this Scheimpflug mounting of the cameras allows for compensating the loss of focus by precisely tilting the camera plane to the lens plane.

The increased computing power available since a few years ago enables calculating cross correlations between the individual positions of particles between the first and second camera image. Imaging magnification and time between the individual laser pulses are known. Therefore, the current flow velocities and directions of the fluid in the measurement plane can be calculated nearly in real time.

Particles and following behavior
The tracer particles in the fluid indirectly communicate information on flow velocities via their motion in the measurement plane. Relevant particle properties in particle image velocimetry primarily include the particle following behavior, scattered light intensity, as well as the number density in the flow field. The objectives are often incompatible because they produce conflicting requirements on particle behavior. For instance, small particles and minimum density difference to the carrier fluid generally yield good particle following behavior. However, scattering light properties benefit from larger cross-sectional areas of particles and increasing density difference. Particle following behavior is generally characterized as an interaction of different forces exerted onto the particles such as resistance, pressures, so-called virtual mass, non-steady acceleration forces, etc.

Micro particle image velocimetry
Micro PIV is a special technique for measuring micro fluid flows via fluorescent scattering particles. In contrast to standard particle image velocimetry, not just a plane but a complete volume is illuminated by laser light. The measurement plane in the volume is then determined by selecting the appropriate f-number (see focal depth) for the microscope lens.

Application example and positioning
ILA GmbH from Jülich, Germany, in cooperation with OWIS GmbH as OEM,
has earned its name in fluid flow measurement technology, in part due to their motorized remote tilt mount (Fig. 3).

The complete system is turned using an OWIS DMT series rotary measuring stage DMT 100 (lilac in Fig. 4). This precision positioning stage, driven by a DC motor, guarantees repetitive accuracy below 0.01°. The stage which can rotate more than 360° here tilts the complete system by up to 270°.

In order to produce the Scheimpflug effect, the tilting angle between camera and lens is adjusted using a DMT 65 rotary measuring stage (dark blue in Fig. 4). It offers a repetitive accuracy better than 0.02°. The lens is connected to the camera only via bellows. Using the second rotary stage, it can be rotated across an angle of 20° relative to the camera axis.

The system will rarely require manual adjustment of the lens in the X- and Y-directions relative to the camera plane. However, if needed, it is performed using an MKT 40C manual miniature stage (green in Fig. 4). The stage has a dovetail guide and is equipped with a fine thread screw with 0.25 mm spindle pitch per revolution for precise positioning.

The complete system is mounted on the OWIS system rail S 65 LL with long holes and RT 65 slide (pink in Fig. 4). Their solid clamping guarantees secure hold and they are available either with knurled or hexagon socket screws.

The remote tilt unit is adaptable to all common PIV camera models allowing customers to employ their own custom PIV technique.

**Basics of laser Doppler velocimetry**

Laser Doppler velocimetry (LDV) is also referred to as LDA (laser Doppler anemometry). Here, measurement relies on the Doppler frequency shift of light waves scattered by tracer particles.

This non-contact optical measurement procedure determines velocity components at one point in a flowing fluid (Fig. 5). Laser light is employed which is monochromatic and coherent. In this technology, the laser is initially separated into two parallel beams using a beam splitter. An achromatic lens then focuses the two beams onto a spot in the flow field. At this point, superposition of the light beams produces an interference fringe pattern.

The particles following the fluid and passing through the focus point scatter the laser light. This scattered light is collected in a photodetector and converted into an electronic signal.

The fringe distance is calculated from the known laser wavelength and the total optical setup of the LDV probe. Fringe distance and measured Doppler frequency then allow calculating the velocities. Thus, the measuring apparatuses do not require any calibration.

**3D laser Doppler velocimetry**

If several LDV systems are employed, several components of the flow field may be acquired simultaneously. This allows assessing flow dynamics in all three velocity components.

**Particles and following behavior**

This technology also requires a careful selection of tracer particles. The same prerequisite as above is that particles need to follow the fluid flow truly and without delay. Also, the particles should not develop any sort of own dynamics in the fluid. In gases, this is ensured by selecting very small particles with less than 1 µm in diameter. Liquid fluids usually carry natural suspended matter so that dotting with particles is rarely necessary.

**Application example and positioning**

The wide range of LDV probes offered by ILA GmbH and supplemented with OWIS linear precision technology is shipped to the customers according to their needs.

FP50 1D and FP50 2D probes in Fig. 6 and Fig. 7 are adjusted using an MKT 40B miniature XY stage. This setup allows for direct coupling of scattered light into the optical fiber. The complete probe is securely mounted on the S 65 LL rail of an SYS 65 beam handling system.

In order to enable adjustment of the measurement probe relative to the measuring spot, the probe is mounted onto a three-axis setup. The three OWIS LTM 80 series precision XY stages each contain a DC drive and feature a repeatability below 15 µm (Fig. 6 and Fig. 8). The system is controlled using LabView and the PS 35 universal positioning control by OWIS GmbH.

Both measurement methods – PIV and LDV – are important measurement principles for investigating fluid flows in gases and liquids. They deliver the necessary information for life-saving medicine technology.

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