Three-dimensional, three-component velocity measurement in an inclined micro-round tube

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A tentative study on a technique for measuring the full field (x,y,z,u,v,w) velocity distribution of the fluid flow at the micrometer scale using single high-speed camera, an epifluorescent microscope, a CW laser, and a piezo actuator. To investigate the three-dimensional (3D) flow structures on a microscopic scale flow, 3D scanning micro-particle image velocimetry was applied to the inclined micro round tube.

On the micro/nanoscopic scale, the dominant factors affecting fluid dynamics are completely different to those on the macroscopic scale, in particular, surface tension and electrostatic forces are much greater than inertia forces. Thus, the investigation and understanding of fluid dynamics at this scale is indispensable for the efficient design and development of new micro/nanofluidic devices. In many applications of micro fluidic devices, the flow is three-dimensional. To investigate the flow behavior correctly in these systems such as chaotic mixers or micro vortex separation devices, full field measurements including 3D (x, y, z) and 3C (u, v, w) velocity information should be carried out.

A three-dimensional (3D) scanning micro-PIV technique having a micrometer scale spatial resolution is applied to an inclined micro round tube to develop the 3D-3C velocity measurement technique with a formerly known out of plane velocity component.

The flow in a micro-round tube was visualized using fluorescent particles. The test fluid was pure water which was pressure-driven at a constant flow rate using a 100 μL microsyringe pump in a 10^0 inclined micro-round tube. The fluid was illuminated with a Nd:YAG CW laser (532 nm) positioned below the microscope stage. To visualize the internal flow, fluorescent particles of 1.0 μm diameter were seeded into the water at a concentration of 0.4 % by volume and were uniformly dispersed. The fluorescent particles absorb green light (~535 nm) and emit orange light (~575 nm). The flow images were captured using a high-speed CMOS (Complementary Metal Oxide Semiconductor) camera (512 x 512 pixels, 10-bit grayscale, 6000 frames/s) capable of recording 8000 images via an epi-fluorescence microscope equipped with an optical filter (λ = 550 nm) and a water-immersion objective lens (M = 60, NA = 0.9, depth of field =6.2 μm).

The amplitude of the present piezo actuator was proportionate to the input voltage. When the input voltage was 12.0 V, it corresponds to a 100.0 μm displacement. The frequency of the piezo actuator closely followed that of input signal over the range 1 Hz to 15 Hz. The piezo actuator follows the sine curve of the input signal. If the amplitude is 50.0 μm and the total scanning distance is 2 x 50.0 = 100.0 μm.

Calculation procedure composed of two essential parts. First one is the instantaneous in-plane velocity measurement, the other one is the out of plane velocity measurement. Since the latter is currently under development some explanation about the tentative results and also some explanation about the methods are going to be presented in this report.

Instantaneous velocity vector maps are calculated using window deformation iterative multi grid (WIDIM) image distortion interrogation algorithm. Images are interrogated with 64x64 pixels 50% overlapped interrogation window (IW) initially and ended with16x16 pixels (4.3x4.3 μm) IW size with 8x8 pixels (2.2x2.2 μm) vector grid spacing. Optical flow images are generated in order to demonstrate the relative behavior of the particle images to the moving lens. They were visualized as the line patterns in the optical flow images in different lengths according to the direction of the phezo actuator.

In two time sequential micro or macro PIV images, if they are correlated and then they are deformed with respect to the half of the in-plane displacements they will become almost the same. If the image recording device, laser sheet or objective lens is moving in the direction of the out of plane displacements, particle images in two sequential images are not same but still there is a similarity. In this study, we investigated the alteration of the correlation peak height in the time domain. Gradient of the cross-correlation is strongly related with the dept-wise velocity component.

Correlation peak height alteration captured clearly in time sequential image assemblies. From these correlation gradients, extraction of depth-wise velocity component could seem to be straight forward, however, it still needs huge improvements in the aspect of the correlation algorithm and post processing which includes generation of calibration curve for a particular phezo actuator characteristics.

Experimental setup for the 3-D scanning micro-PIV system.