Optimizing a holographic PIV system using a Bacteriorhodopsin film

Thomas Ooms[1], Joseph Braat[2], Jerry Westerweel[3]

1: Faculty of Mechanical Engineering, Delft University of Technology, The Netherlands, t.a.ooms@wbmt.tudelft.nl
2: Faculty of Applied Sciences, Delft University of Technology, The Netherlands
3: Faculty of Mechanical Engineering, Delft University of Technology, The Netherlands

Keywords: Holographic, PIV, Bacteriorhodopsin, Three-dimensional flow measurement

Since the 1990's, impressive 3-dimensional holographic particle image velocimetry (HPIV) measurements have been performed using silver-halide based film. However, the inconvenience and time-consuming nature of chemical processing of the film stimulated further research. Digital HPIV led to only limited results due to the limited information capacity of present electronic sensors. When bacteriorhodopsin (BR) was presented in 2000 as a high-resolution optical memory, its potential as a recording medium for HPIV was quickly realized because it does not suffer from the disadvantages of the other techniques.

This work investigates the amount of particles that can be recorded on a BR-film and reconstructed with sufficient signal-to-noise ratio (SNR) to allow the extraction of velocity vectors with a correlation analysis. This particle number is an important indication, because it is directly related to the number of flow velocity vectors that can be extracted. The number of recorded particles is a result of the illuminated cross-section area of the flow volume and the particle-integrated-area-density (= product of the particle-number density, n_s, and the longitudinal dimension of the flow volume, L). These values are limited by the laser pulse energy, scattering efficiency of the tracer particles, the speckle noise caused by out-of-focus tracer particles and by scattering from the BR-film and thermal noise of the CCD camera.

The illuminated cross-section area and the particle-integrated-area-density are maximized by applying small, strongly scattering tracer particles, adding a high-pass optical Fourier filter to the recording set-up, optimizing the energy ratio between the object beam and the reference beam and optimizing the intensity of the reconstruction beam. Investigation of the reconstructed-particle-image-intensity and the intensity of various noise terms, has led to an optimal object-beam diameter of 32 mm.

The maximum amount of particles that can be recorded on a BR-film and reconstructed with sufficient SNR is experimentally determined. Strong scattering with small particles is achieved by using hydrogen bubbles as tracer particles. They are generated by electrolysis of water and form a well-defined plane of slowly rising particles. This particle field is holographically recorded and reconstructed. The particle-integrated-area-density is varied between different recordings. A 3D-correlation is performed with a varying transverse interrogation volume size of 128, 64, 32, 16 and 8 pixels (pixel size 6.45 μm). For an intermediate value of the seeding density and a transverse interrogation volume size of 8 pixels, about 11.000 interrogations yielded a correct velocity vector. It is assumed that each of the 11.000 interrogation volumes contains at least one tracer particle. Only a part of the reconstructed particle field is recorded by a CCD camera and analyzed. To calculate the total number of particles that are successfully recorded on the BR-film, the value of 11.000 should be multiplied by the ratio of the cross-section area of the illuminated flow volume (~800 mm^2) and the area of the CCD chip (~34 mm^2). This leads to the conclusion that more than 100.000 particles are recorded on the BR-film and reconstructed with sufficient SNR to yield correct velocity vectors with a correlation analysis. This value is confirmed by measuring the hydrogen-bubble-volume-flow and the volume of a hydrogen-bubble which are used to calculate the number of recorded particles.

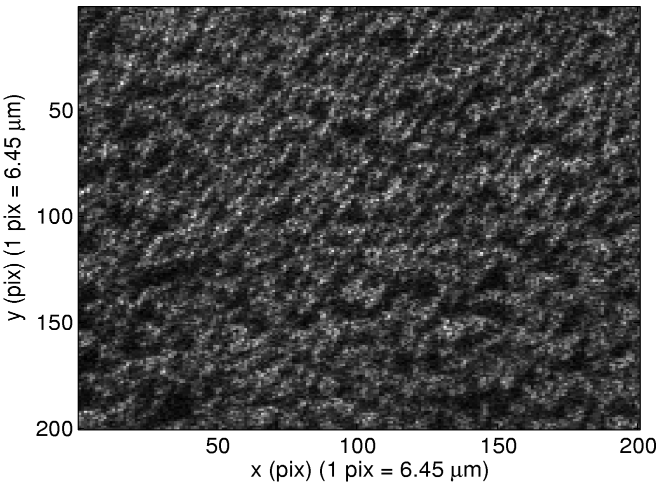

Fig 1. Holographic reconstruction of the hydrogen bubble field.

A part of the flow near a vortex ring in water is recorded and analyzed to illustrate the system's ability to perform realistic flow measurements.

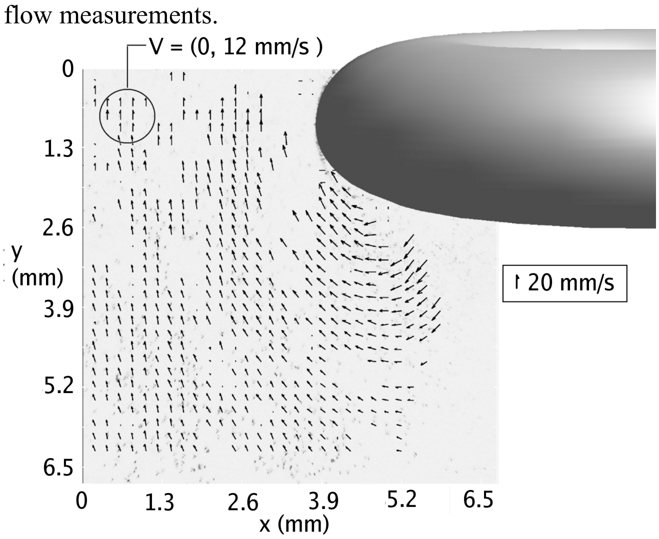

Fig 2. Velocity field near a downward traveling vortex ring. The drawn vortex ring is added for clarity.