P2-15

Measurement of Particle Location using Laser Holography

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1 Introduction

Three-dimensional flows have been measured using PIV (Particle Imaging Velocimetry) by several researchers. It is proposed that laser holography is applied to record unsteady three-dimensional flow structure. However, the reconstructed image is known to be expanded in the depth direction of the object beam. To determine the depth coordinate of the reconstructed object image, a camera is moved at a small predetermined step in the depth direction of the object beam. When the reconstructed object image becomes in focus, its depth coordinate is obtained from the displacement of the camera (Trolinger et al., 1997). Reconstructed object images are viewed from two different directions, and the coordinates of the objects are obtained (Fabry 1998, Meng et al., 1995). Velocity vectors are measured from (1) vectors in the direction where particles expand and (2) displacement of the particles at two consecutive time on two-dimensional plane (Barnhart et al., 1994). As compared with these methods, our research employs a method for a simple optical layout and principle to measure particle locations in 3-D. A series of x-y cross-sections of reconstructed image are captured at every short interval in z-direction (the proceeding direction of the object beam). The rearrangement of the stack of x-y cross-sections produces a stack of x-z and y-z cross-sections. It is proposed that the center of gravity of the object is determined from the x-y, y-z, and x-z cross-sections of the object image by the moment method. This method is verified.

2 Experimental Apparatus

Figure 1 shows a top view of an optical system put on an optical base with a vibration isolator. Laser beam from an Ar-Ion Laser (wavelength: 514nm) led to a beamsplitter (BS), and was divided into an object beam and a reference beam with the beamsplitter (BS). The object beam was diverged with a convex lens (L3) and frosted glass (G). Passing the object, the object beam fell perpendicularly onto a holographic plate. The reference beam was expanded with two convex lenses (L1), (L2), and irradiated the holographic plate. At this time, the optical setup was arranged so that the optical path of the object beam might equal that of the reference beam. z-axis was defined as the direction of the object beam. x-axis was defined as the direction which was parallel to the surface of the optical base and was perpendicular to z-axis. y-axis was defined as the vertical direction to the optical base.

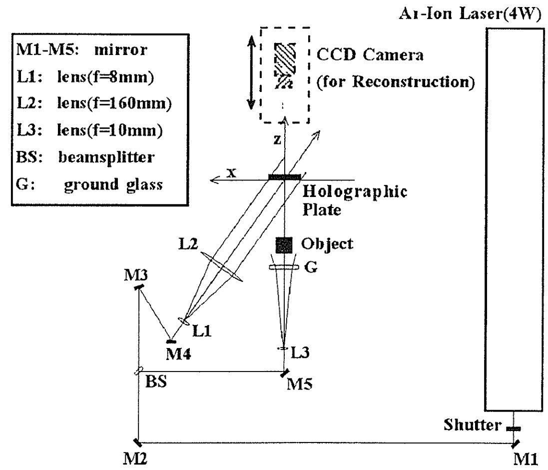

Figure 1 Optical system

Screen project method was used for capturing the reconstructed image of hologram. A screen and a CCD camera were fixed on a traveling base, and the two-dimensional cross-section (x-y cross-section) of the reconstructed image was acquired every 1 mm in the depth direction (in z-axis direction).

3 Image Processing and Measurement of Center of Gravity

(1) Rearrangement

The x-y two-dimensional cross-section image (150 pictures) of 560pixel × 400pixel (51mm × 36mm) was captured every 1 mm in the z-direction by the CCD camera. Collecting the same horizontal line from 150 x-y cross-sections of the image produced a x-z cross-section of the image. After this procedure is repeated along y-direction, 400 x-z cross-section images are obtained. Similarly, the y-z cross-section images were produced.

(2) Processing for original image

The original images contain the various noises. Midian filter was used for removing noises. After operating midian filter on x-z cross-sections, they were transformed into the x-y plane. Furthermore, the transformed x-y plane was operated with midian filter. Next, the background of each x-y cross-section image was removed by using 2D Rolling Ball of NIH Image, and the images were binarized using a threshold value which was calculated by Otsu's method (Otsu 1980). In the same way, binarized y-z cross-sections were obtained. Consequently, the reconstructed three-dimensional image can be viewed from each x-, y-, and z-direction on a personal computer.

(3) Measurement of the centers of gravity of particles

At first, particles of binarized image were labeled in the three-dimensional space. The center of gravity for each particle in the z-direction was obtained from 150 pictures of x-y cross-section image by the moment method. Similarly, the centers of gravity of the particles in the y-direction were determined from 560 pictures of x-z cross-section image, and the centers of gravity of the particles in the x-direction were obtained from 400 pictures of y-z cross-section image.

(4) Calibration coefficient

Before the positions of particles are measured, each x-, y-, and z-coordinate must be calibrated. A transparent sheet where round marks were drawn on the grid of 2.5 mm interval was placed vertically, and was recorded by laser holography. The calibration coefficients Cx in x-direction and Cy in the y-direction were calculated from the reconstructed round marks' position and those real position in x-y plane. White plastic balls of with a diameter of 2 mm were recorded at a known interval in the z-direction. From the reconstructed image, the calibration coefficient Cz in z-direction was determined.

4 Results

Figures for Cx and Cy are omitted owing to the space of this paper. x- and y-coordinates of the particles were measured by using Cx and Cy. Figure 2 shows calibrated results. Measured center of gravity positions (z-direction) of particles by the present method are plotted against those of the real positions. It is seen that the center of gravity of particles in the z-direction can be measured precisely by the present method.

A rising bubble in a container (width 50mm, depth 50mm, height 250mm) was recorded by laser holography. The container filled with glutinous starch syrup. The glutinous starch syrup was used to make the bubble rising velocity low. The three-dimensional image reproduced by the present method is indicated in Figure 3. This figure shows that small bubbles hide behind a big bubble, and that the size and the position of the bubbles can be measured. The surface color (shade) of the bubble in the figure represents the position in the z-direction.

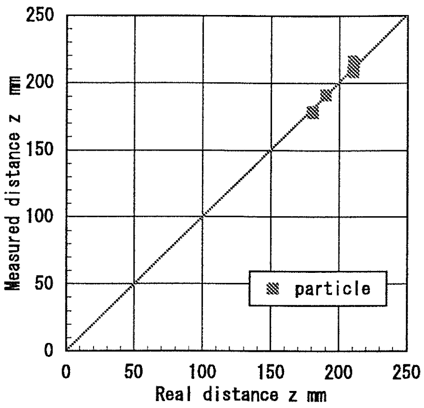

Figure 2 Center of gravity in z-axis direction

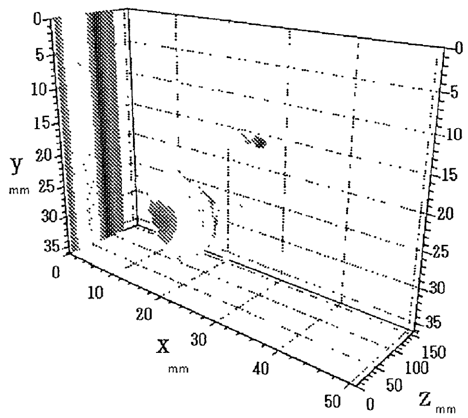

Figure 3 Reconstructed image

5 Conclusions

(1) It was shown that an object image was extracted from the holographic reconstructed image with the image processing described at this paper, and that the rearrangement of the stack of x-y cross-sections produced a stack of x-z and y-z cross-sections.

(2) It was proposed that the center of gravity of the object was determined from the stack of the x-y, y-z, and x-z cross-sections of an object image by the moment method. This method was verified.

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