Three-dimensional measurement with two cameras of a turbulent pipe flow by digital holographic-PTV

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ABSTRACT

Three-dimensional simultaneous measurements of velocity field in a turbulent pipe flow are performed by digital holographic velocimetry. We proposed holography technique with two laser beams. For this study, the Reynolds numbers was set to be 15000. The accuracy of the experimental method was confirmed by comparing the results from the method with DNS data by Satake et al. [4] when using the same Reynolds number. The velocity profiles obtained from the method was found to be in good agreement with that of the DNS data.

INTRODUCTION

Three-dimensional simultaneous measurements of velocity field in a turbulent pipe flow are performed by digital holographic velocimetry. J Soria and C Atkinson [1] proposed holography with two or three laser beams. Their method was established for measuring the velocity in jet flow. We also proposed holography technique with two laser beams. The seeding particles in a turbulent pipe flow can be reconstructed by a digital hologram [2-3] using two cameras. And then we compared the DNS data. Our objective here was to check the validity of the experimental method. For this study, the Reynolds numbers was set to be 15000. The accuracy of the experimental method was confirmed by comparing the results from the method with DNS data by Satake et al. [4] when using the same Reynolds number.

EXPERIMENTAL SETUP

Figure 1 is a schematic of the experimental setup showing the path of a laser beam from a single source. A Nd:YLF laser (Photonics Industries DS20-527, λ= 527 nm) was used as a light source putting out a pair of laser pulses at a repetition rate of 1 kHz, pulse length of 58 nsec, and a pulse delay of 100 μsec. The laser beam was expanded to illuminate the center of a test section. A pipe made of FEP, 3000 mm in length, and 20 mm in diameter, was used for the test. The test section located at 2800 mm downstream from a water tank was made of glass to preserve the coherency of the laser beam. A water jacket (length = 55 mm, width = 45 mm, and depth = 40 mm) shown here, was also made of glass. Using a pump, the working fluid (water) was circulated at flow rate of 14.2 l/ min, with Reynolds numbers as 15000. Spherical particles of nylon, 40-micron in diameter, were supplied for conducting the test. The hologram fringe images were captured through a digital CCD camera (IDT NR5S2) without a lens, with a resolution of 2336 x 1728 (7 μm / pixel). The captured image at 1 k Hz, used 1024 x 1024 in the full image area. Our system was designed to make a velocity field of four hundred frames so that the system could handle 800 frames by the camera memory of 1 k Hz for a sampling rate. The split laser beams by half mirror after passing through the beam expander were introduced horizontally into the Camera 1 and vertically into the Camera 2 in Fig. 2. The Camera 2 has two positions to measure the observation regions distinguished by the pipe center and pipe wall in the water jacket. In order to calibrate the measurement system, we have prepared mark patterns onto a quartz substrate in Fig. 3. The mark patterns were fabricated by electron beam lithography and lift-off technique. In this case, the chromium layer, whose thickness was about 100 nm, was employed to mask the green laser beam. The diameter and the pitch size of mark pattern were 200 μm and 50 μm, respectively.

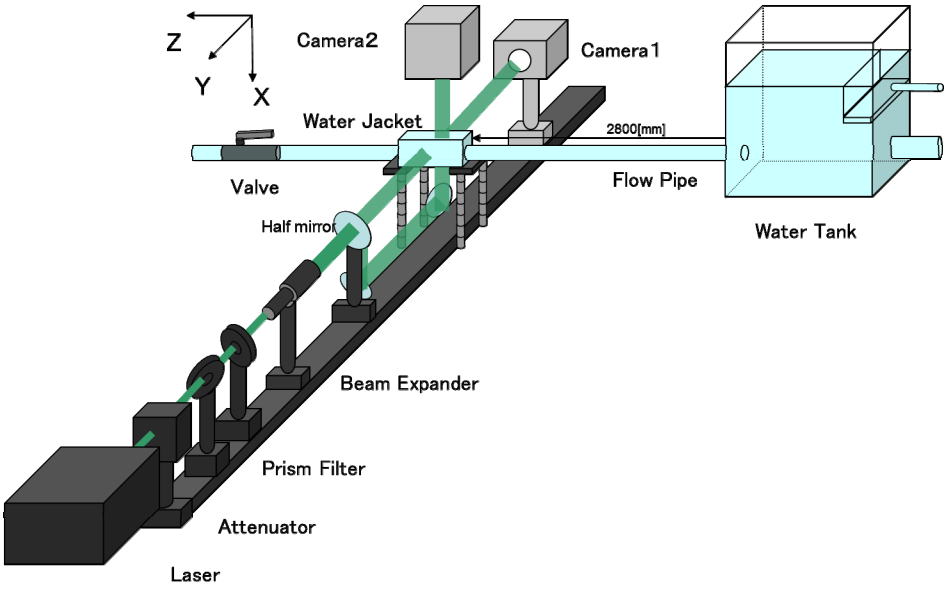

Figure 1 Experimental apparatus.

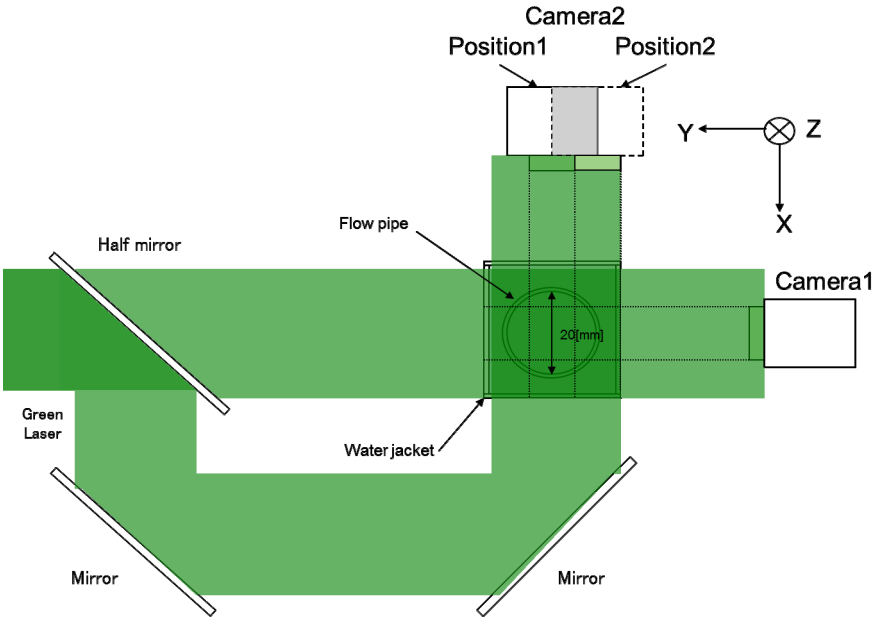

Figure 2 Optical setup

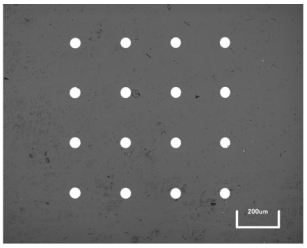

Figure 3 Marking points on the calibration plate.

RESULTS AND DISCUSSION

Figures 4 (a) and (b) show the particles reconstructed by two cameras in the pipe. These figures show each position in the Camera 2, respectively. The reconstructed particles merged in the central region of the pipe in Fig. 4(a). The reconstructed particles merged near wall region of the pipe in Fig. 4(b).

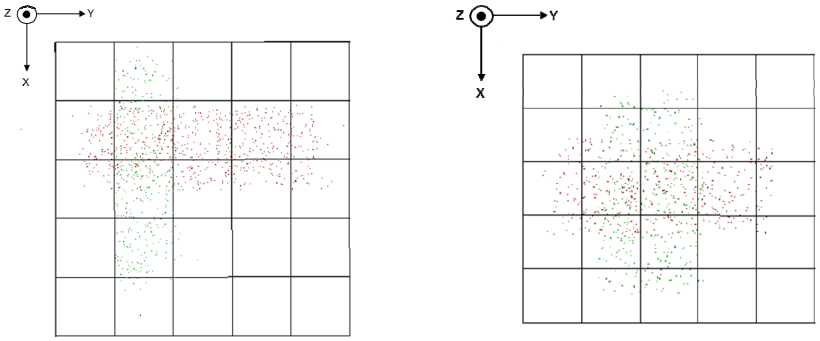

Figure 4 3D reconstructed particles by two cameras; (a) Position 1, (b) Position 2

Figures 5-8 show the velocity profile. The profiles obtained by two regions in Figs. 4 (a) and (b) are drawn in the same figure. In the experiment with DHPTV, the reconstruction layers in the z-direction were 2000 sections. Thus, this three-dimensional reconstruction volume (in pixel points) was 1024 x 1024x 2000 along x-, y-, and z-directions each camera. To obtain an averaged velocity profile, the average volume divided by 60 sections in the cross-section of the pipe diameter, and 400 frames were used. All velocity profiles were normalized by the centerline velocity Uc on the each method. The DNS data by Satake et al. [4] are also shown in the same figures. The velocity profiles obtained by the DHPTV are in good agreement with that of the DNS data.

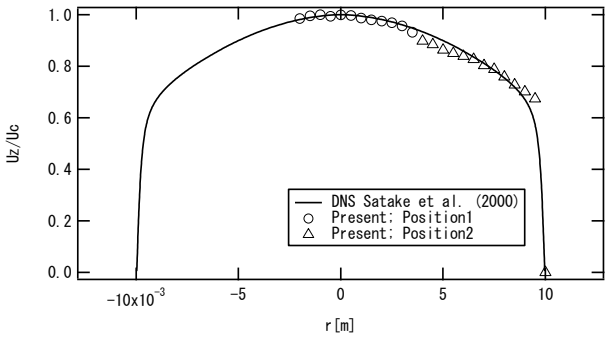

Figure 5 Mean velocity profile.

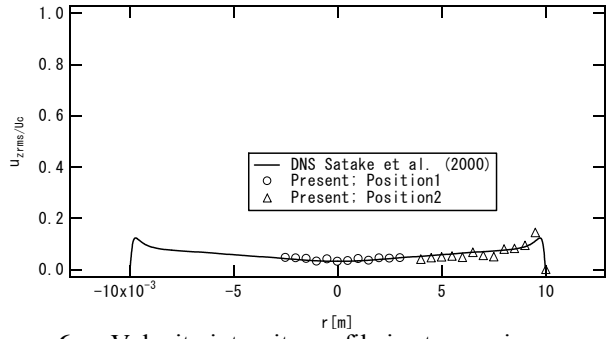

Figure 6 Velocity intensity profile in streamwise component.

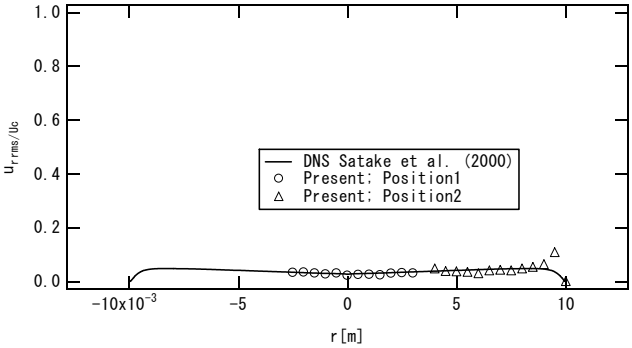

Figure 7 Velocity intensity profile in radial component.

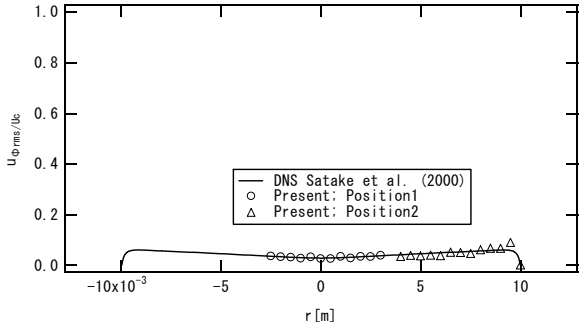

Figure 8 Velocity intensity profile in circumferential component.

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