Development of a Holographic Particle Diagnostic System and Its Application to Measurements of Spray Characteristics

Y. J. Choo  
Korea Atomic Energy Research Institute,  
105, Yuseong-Gu, Daejeon 305-600, Korea

B. S. Kang*  
Department of Mechanical Engineering, Chonnam National University,  
300, Yongbong-Dong, Buk-Gu, Gwangju 500-757, Korea

Particle diagnostics involving three dimensional distributions are important topics in many engineering fields. The holographic system is a promising optical tool for measuring three dimensional features of particles. In this study, we developed a holographic particle diagnostic system with diffused illumination to measure the sizes and 3-D velocities of moving particles using automatic image processing. First, basic optical systems for pulse laser recording, continuous laser reconstruction, and image acquisition were constructed. One of inherent limitations of particle holography is its long depth of focus in particle images, which causes considerable difficulty in determination of particle positions in the optical axis. To solve this problem, three new auto–focusing parameters (AFPs) corresponding to particle sizes were introduced. The developed system was applied to spray droplets to validate its capabilities. Three dimensional positions of particles viewed from two sides were decided using AFPs and then three dimensional particle velocities were extracted using a particle tracking algorithm. Comparison of measured sizes and three dimensional velocities of particles with those obtained using a laser instrument, PDPA (Phase Doppler Particle Analyzer), showed that the developed holographic system produced consistent results.

Key Words: Holographic Particle Diagnostic System, Diffused Illumination Holography, Particle Tracking, Focusing Parameter, 3D Particle Position

**Nomenclature**

\( D \): Particle diameter  
\( E \): Position error of particle  
\( R \): Moving distance of particle  
\( \Delta t \): Laser pulse interval  
\( u \): Uncertainty  
\( V \): Particle velocity  
\( X, Y \): \( x \) and \( y \) axis  
\( Z \): \( z \) axis (optical axis)

**Subscripts**

\( I \): CCD sensor  
\( p \): Reconstructed particle

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* Corresponding Author,  
  **E-mail**: bskang@chonnam.ac.kr  
  **TEL**: +82-62-530-1683; **FAX**: +82-62-  
  Department of Mechanical Engineering, Chonnam National University, 300, Yongbong-Dong, Buk-Gu, Gwangju 500-757, Korea. (Manuscript Received May 8, 2006; Revised October 20, 2006)

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1. Introduction

The particle flow fields encountered in many engineering areas have many complexities and irregularities, and a three dimensional nature. To investigate the characteristics of such particle flow fields, various measurement techniques and instruments have been developed and commercialized. Among these, non-intrusive optical instruments, such as Imaging, LDV (Laser Doppler Velocimetry), PDPA (Phase Doppler Particle Analyzer), PIV (Particle Image Velocimetry), have
advanced remarkably, because of rapid laser, imaging system, and computer developments. However, a measurement tool capable of determining 3-D features of particles over a complete test volume as a function of time remains on the developmental wish-list. In recent years, much experimental efforts have been made to try to overcome limitations of 2-D measurements, for example, stereoscopic PIV system for 3-D velocity measurements. From this point of view, a holographic method probably offers the ultimate solution, because of its superiority at realizing 3-D fields in itself. However, many problems must be overcome, and holographic systems very much remain at the developmental level.

As for spray diagnostic systems, considerable progress made in laser instrument technologies like PDPA, which now makes it possible to obtain reliable data on droplet sizes and velocities in dilute spray regions. However, these methods are inherently limited in dense spray regions, where liquid elements are rather large and non-spherical. In addition, no information on spray structure can be provided by this kind of instrument. On the other hand, the holographic technique reproduces the frozen spray as a 3-D image, from which droplet sizes and position, 3-D velocities and spray structures can be investigated.

From early years, the holographic technique obtained great interests of researchers owing to methodological possibilities of particle diagnostics and 3-D flow measurements (Vikram, 1979). The holographic system for 3-D flow field measurements is Holographic PIV, which extends the correlation technique used in 2-D PIV to three dimensions. HPIV has been improved remarkably to satisfy strong demands of 3-D features (Barnhart, 2001). Like conventional PIV, HPIV concerns only about flow fields using scattered spots by particles. On the other hand, the holographic system for particle diagnostics can measure the shapes, sizes, velocities, and 3-D positions of individual particles which are important parameters in many particle fields. Unlike HPIV, few works related to particle diagnostics have been conducted so far in the limited range (Haussmann and Lauterborn, 1980; Kang, 1995; Feldmann et al., 1999).

Haussman and Lauterborn (1980) measured gas bubbles in water using the automated digital image processing system. The focusing parameter using the differential filter was introduced. However, they concluded that primary limitation was imposed by low spatial resolution of image device (roughly 38 μm) and long calculation time. Feldmann (1999) obtained more successful and quantitative results for the moving bubbles and spray droplets. They measured the 3-D positions of particles using stereo-matching of particle images reconstructed in two sides. However, he didn’t attempt to compensate geometry distortion made by wavelength difference between recording and reconstruction stages. Kang (1995) used a two-reference-beam double–pulse technique, which featured switching the polarization of the laser light between pulses to separate the first and second droplet images, thus avoiding the overlapping problem and the directional ambiguity of particle movement. The method developed was applied to fan-shaped sprays formed by two impinging high-speed jets.

In the present study, a diffused illumination holographic system was developed to measure the sizes and 3-D velocities of moving particles using automatic image processing. Initially, basic optical systems for pulse laser recording, reconstruction with a continuous laser having a same wavelength with the pulse laser, and image acquisition were constructed. One of inherent limitations of particle holography using forward scattered light is its long depth of focus in particle images. This characteristic causes considerable difficulty in determination of particle positions in the optical axis, and prevents full automation of holographic image processing from image capture to particle characterization in space and time. To solve this problem, three auto-focusing parameters (AFPs) corresponding to particle sizes were introduced and verified by present authors (2006). The developed holographic velocimetry system was applied to real spray droplets to validate its capabilities. Three dimensional positions of particles viewed from two orthogonal sides were decided using AFPs, and then three dimensional particle velocities were extracted using a particle tracking algorithm. Measured sizes and three dimensional