REVIEW ARTICLE

Holographic particle image velocimetry

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Abstract
Holography is truly the key to three dimensions in particle image velocimetry, i.e. the measurement of all spatial components of the velocity vector—and this over a deep measuring field. Sophisticated instruments have been designed that successfully tackle practical problems such as the low scattering efficiency of particles, the inferior depth resolution or the aberrations and distortions in the reconstruction. Furthermore, efficient strategies are introduced to interrogate the holographic storage and process the huge amount of data towards a final flow field representation. Recently, phase-sensitive metrology, familiar in many fields of experimental mechanics, has been examined for use in particle velocimetry. Suitable methods are holographic and speckle interferometry or the optical processing of data for three-dimensional correlation. While in these techniques the power of optics is unrivalled, the practical advantage of video and digital techniques over photographic recording is obvious. The electronic version of speckle interferometry (ESPI/DSPI) is a well-established method used in laser metrology and has received further exploitation for applications in flow analysis recently. Finally, the state-of-the-art of digital particle holography is reviewed to allow estimates of its future in experimental flow analysis.

Keywords: fluid flow velocity, holography, holographic interferometry, speckle interferometry, flow diagnostics, particle image velocimetry (PIV)

1. Introduction

Today, the challenges in fluid dynamics research concern complex three-dimensional non-stationary flows. It is generally agreed that there is a considerable developmental need for diagnostic tools that cope with these demands. Thus, extensions of well-established particle imaging techniques towards higher dimensionality are topics of increasing interest. While the supplementation of classical PIV towards a stereoscopic metrology has become standard to obtain three-component (3C) velocity data, the coverage of all of space (3D) requires the specific adaptation of holography to the registration of critical objects such as micron-sized tracer particles. It is interesting to note that some of the very early objects in quantitative holographic metrology were small particles—some 35 years ago (cf the review by Vikram (1990)). However, finding the economic means to extract and process the immense amount of data available in a single hologram of a flow scene has required researchers to wait for the development of sophisticated electro-optic instrumentation and fast digital hard- and software.

Holography for particle velocimetry has revived the role of optics in flow diagnostics. Traditional PIV, originally a predominantly optical method not only in the photographic recording of particle images, but also in large parts of the interrogation procedures, has matured into a robust and efficient method by using CCD-cameras and digital image processing. Pioneers in the field still recall that two-dimensional Fourier transformations were performed optically by creating Young’s fringes. A museum of PIV would have to put on display the many ingenious inventions to speed up the production and processing of these fringes. Examples are the purely optical correlation using an optically addressable spatial light modulator (OASLM) (Vogt et al 1994), high-speed automatic processing employing a network of modulators, deflectors and detectors (Mao et al 1993) or the parallel optical processing of a photographic PIV-record introducing a synthetic holographic array of micro-lenses to avoid the time needed to scan the photo sequentially (Arnold and Hinsch 1989). When the pioneers met, there were nostalgic reminiscences of those days.

The successful implementation of stereoscopic viewing provides a good example showing that, even today, optics should be exploited to their very best before digital improvements are applied. Good depth resolution requires...