Experimental Fluid Mechanics

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Speckle Photography for Fluid Mechanics Measurements

With 83 Figures

Springer

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Preface

Starting from Burch and Tokarskii's experiments in 1968 [1], during the last three decades *speckle phenomena* have been extensively investigated for use in *speckle metrology.* The results of the first decade of these investigations were summarized in the first book on the subject which appeared in 1978 (R.K.Erf, ed. *Speckle Metrology*)[2].

During the second decade the field grew and was subdivided into several new metrology areas, like *particle image velocimetry* (PIV), *dynamic speckle methods*, *speckle photography*, and *speckle tomography.* The advances in CCD imaging and computer hardware stimulated the development of *electronic speckle interferometry* (ESPI) and *digital* PIV (DPIV). Holographic PIV (HPIV) and holographic speckle photography (HSP) were introduced recently into this area of metrology.

The application areas of this metrology were also essentially enlarged. Starting from surface inspection, surface displacement, vibration and strain measurements, speckle-based techniques became well established methods in solid and fluid mechanics, astronomy, informatics, and bio-mechanics. Many books have already been published in this field [3-6]. There are a number of fundamental books in very closely related fields of optical diagnostics in fluid flows [7-13]. This book is devoted to the application of speckle photography for fluid mechanical measurements.

Speckle photography nowadays is widely used for fluid mechanics measurements. As in the other applications, the work which gave rise to employing speckle photography in metrology, was the publication of the results of observing diffraction halo in two speckle-fields, registered on the same photographic plate and shifted mutually by a short distance equal to several speckle sizes [1]. The pattern of this diffraction appeared to be identical to the diffraction pattern in two orifices, and it represents the diffraction halo, modulated by Young's interferometric fringes. The distance between these fringes and the angle of their inclination with respect to a coordinate axis are determined uniquely by the shift vector of the speckle field on the photographic plate, which enables, by analysing the diffraction halo, the establishment of the magnitude of the shift with the direction remaining ambiguous. Nowadays, two different optical principles, both of which are based on the speckle technique, are used for fluid mechanical measurements.

One of the methods, *speckle velocimetry*, relies on the use of tracer particles whose motion in the plane of the flowfield is recorded on a photographic plate. To perform these measurements, the laser-light sheet is passed through the flow section, and the seed particles are photographed perpendicular to the plane of the light sheet. Thus, the velocity vectors are determined at each point in the light sheet by a point-by-point interrogation of the obtained photograph.

The second method, *speckle photography*, is based on measuring the deflection angles of the light transmitted through the flow. This technique is a *line-of-sight* method and provides information integrated along the optical path.

The first descriptions of this method were given by Köpf [14,15], by Debrus *et al.* [16], and by Mallick and Roblin [17] as early as 1972, but it was more than a decade before applications of the new technique to fluid mechanical problems were reported [18]. The state of the art of this technique is reviewed in recent publications [19,20].

It is essential that both PIV and line-of-sight speckle photography provide quantitative information for turbulent flows as well. This is due to the universal pattern of Young's interferometric fringes which remain straight and equidistant even for turbulent flows. Such interferometric patterns can be easily read into computer memory using CCD cameras. Direct optical data input into computer memory opens the way to the storage of large amounts of experimental information. This allows one to use these data in tomographic reconstruction of 3D temperature fields and to perform statistical analysis of the flowfield providing data about turbulence.

The purpose of this book is to discuss the modern possibilities of speckle photography based on automated computer-aided specklegram processing, both for the reconstruction of complex 3D refraction index fields and for the estimation of turbulence parameters in fluid mechanical measurements.

The book is divided into 10 chapters. The first six contain a description of speckle photography and the last four contain a description of the application of speckle photography to fluid mechanical measurements. According to this the first chapter (Introduction) contains a very short description of speckle photography, the second one is devoted to diffraction theory, and the third one to speckle statistics. This is a theoretical introduction to speckle photography. The next three chapters are introductions to the experimental technique. The fourth chapter contains the description of speckle generators, light sources, and recording methods for speckle photography. The fifth one contains a description of basic optical schemes for obtaining specklegrams, whereas the sixth one deals with the automated specklegram treatment. The last four chapters are devoted to a discussion of density (temperature) measurements in laminar flows, velocity measurements, and estimation of turbulence parameters in turbulent flows. The last chapter contains a description of speckle tomography, the most promising approach in the tomography of complex phase objects.

The original idea of writing this book was a result of an early attempt to translate into the English language the author's book entitled *Speckle Photography For Fluids Flows Measurements* and published by Nauka i Technika Press, Minsk in 1989 (in Russian) [21]. However, during the decade that has passed since that time, a great number of new results in the field have been obtained. Major progress was observed in the measurement of turbulence parameters and in speckle tomography. These results and approaches occupy a significant part of this book.

For a long time the author's team has had close scientific contacts with Professor Wolfgang Merzkirch's team at the University of Essen. Many measurements were made jointly and many joint projects were developed during the last 15 years. The author is very proud of these relations and would like to express to Wolfgang Merzkirch his deepest gratitude for the friendship and scientific leadership in this very interesting 'speckle field'.

A number of grants and joint projects were very important for the development of the speckle photography technique at the Heat and Mass Transfer Institute, Minsk, Belarus. One of the first is the grant of the International Science Foundation (Soros Fond) RWB 000 as well as the subsequent grant of the Soros Fond and Belorussian Government (RWB 300). I am deeply grateful to the INTAS Foundation for grant INTAS 93-0344 and personally to Professor Clive Greated, Co-ordinator of this project. A number of publications were prepared under the scope of this project and scientific ties have been established between the Heat and Mass Transfer Institute and the University of Edinburgh. During the last decade, joint research projects on speckle photography were developed also with the University of Poitiers under guidance of Professor F.Fisson and Professor J.-B. Saulnier. Last but not least is NATO grant HTECH.LG 961001, scientific co-ordinator Professor W.Merzkirch, which allowed us to extend contacts with Essen University.

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