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OPTICS and LASERS in ENGINEERING

Guest Editorial

Recent developments in digital speckle pattern interferometry

The last 10 years have seen significant developments in the area of digital speckle pattern interferometry (DSPI) aided by a strong support from the developments in image analysis/processing and in computer technologies. A comprehensive review covering most of the concepts, methods and technologies in the field are contained in a recent book [1]. DSPI is an optical measurement technique [2] that combines speckle pattern interferometry with electronic detection and processing, and is widely used in the investigation of a wide range of physical parameters such as displacements, vibrations, strains and surface profiles of engineering structures.

The primary advantages of the DSPI reside in its non-invasive nature of operation and the display of the measurement information in real-time and on whole field basis. The method allows for data storage and retrieval for analysis, enables quantitative evaluation using phase stepping, offers variable measurement sensitivity and provides the possibility to make measurements at remote areas in machines, for example. The basic measurement system consists of an optical head, CCD camera, host computer, image processing system and a TV monitor. A specimen illuminated with an expanded laser beam forms a speckle pattern. The scattered speckle pattern is imaged onto a CCD. A reference wave, which may or may not be speckled is added at the observation plane to achieve interference between the object and reference waves. The resultant speckle pattern is stored in the processor and displayed on the monitor. The object deformation causes a path difference between the wave front scattered from its surface and the reference wave, and, this modified speckle pattern is either subtracted or added to the previously stored pattern and rectified. The bright and dark fringes displayed on the monitor are referred as *correlation fringes* and represent contour lines of constant surface displacement.

For the past three decades series of developments and refinements in terms of optical systems and modern fringe analysis algorithms on the one hand, and high resolution CCD cameras and fast and reliable image processing systems on the other hand, have emerged as the result of efforts of various research groups from academic institutions and industries across the globe [1,3–8].

The optical head of the ESPI system can be configured in several different ways depending on whether the problem at hand concerns the measurement of displacement components (interferometry) or spatial derivatives of displacement components (shearography). The optical devices to yield in-plane displacement components of a deformation vector are classified as (i) dual-beam symmetric illumination—normal observation [2], (ii) oblique illumination—observation [9], (iii)

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normal illumination—dual direction observation [10] and (iv) dual-beam symmetric illumination—observation [11–14]. In dual-beam symmetric illumination—observation configuration, the scattered fields from the object are observed along the direction of illumination beams and they are either imaged as two separate images or combined into one at the observation plane. While the arrangement [14] senses the in-plane displacement with sensitivity proposed by Leendertz [2], the one described in [11,12] yields two-fold increase in sensitivity. A photograph representing two sets of correlation fringe patterns with identical measurement sensitivities and observed simultaneously on the monitor is shown in Fig. 1.

Similarly, several optical configurations have been developed for out-of-plane displacement measurements to cater to different measurement needs. These methods, which also feature the possibility of modifying the sensitivity of measurements, are based on (i) in-line reference wave configuration [15,16], and (ii) off-axis reference wave configuration [17–19]. The use of optical fibers has in addition paved the way to the development of portable ESPI systems with the possibility for the system to be implemented in remote conditions [20–24]. Figs. 2 and 3 show typical examples from non-destructive evaluation of a honeycomb structure and vibration studies [25] of an Indian classical music instrument, respectively. Some novel approaches for evaluating displacement components from a single optical unit are given in Refs. [26–29].

Offshoot of interferometric arrangements in DSPI, shearography offers an interesting approach to obtain the derivatives of displacement components. The technique has found a wide use in aerospace industry for non-destructive evaluation of spacecraft structures. A Michelson type of shear interferometer [30] is generally employed to introduce lateral shear in an optical configuration [31–33]. A universal shear interferometer has been proposed to implement lateral, radial, rotational and inversion shear in ESPI [34]. Dual-beam symmetric illumination in a Michelson

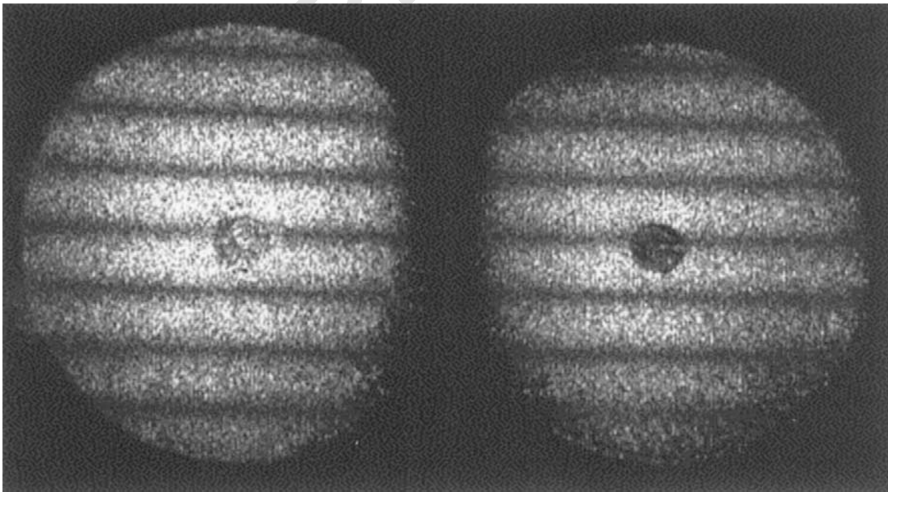

Fig. 1. Speckle correlation fringes obtained in a dual-beam symmetric illumination—observation system.

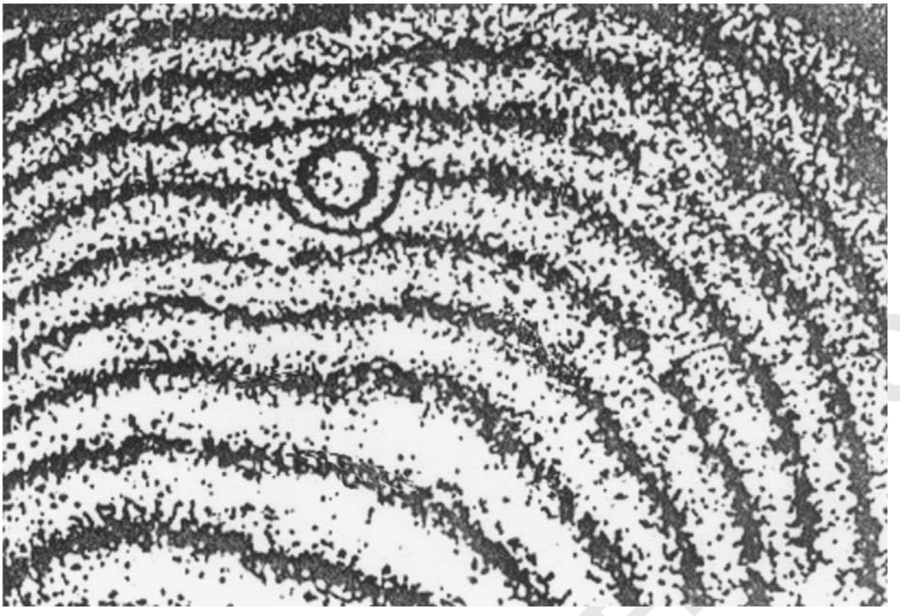

Fig. 2. Non-destructive evaluation of debonds detection in a honeycomb panel.

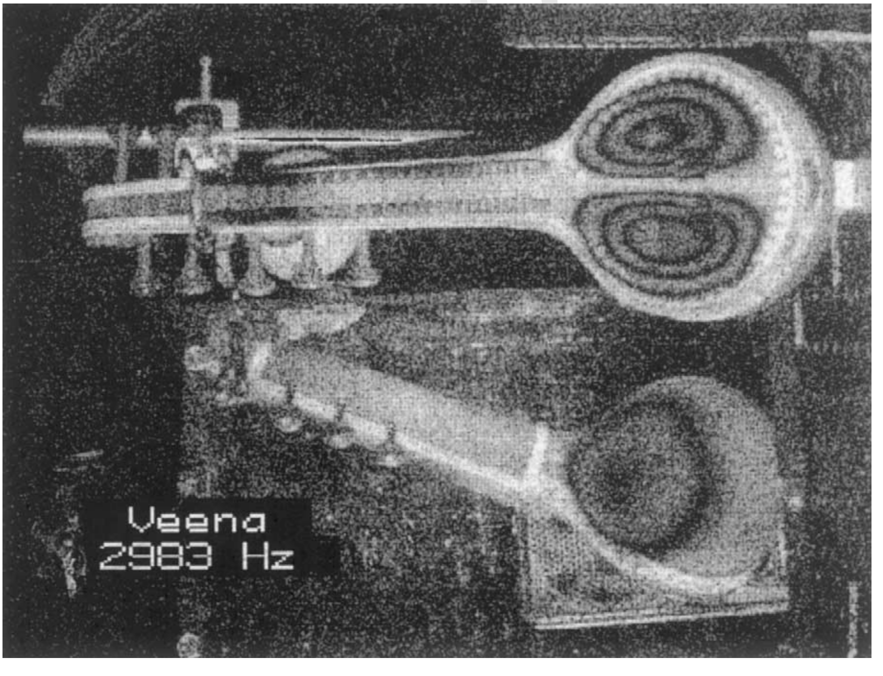

Fig. 3. Time-average fringe pattern on *Veena*, an Indian classical music instrument.

shear arrangement [35–37] has been used for obtaining the partial derivatives of in-plane displacements. The other prominent shearing devices are: split lens, shear element [38], birefringent crystals [39,40] and holographic optical elements such as holo-shear lens [41], and holo-gratings [42]. Of the many salient developments, the two that one could probably cite here concern the simultaneous measurement [43] of out-of-plane displacements and their derivatives, and the measurement of second-order partial derivatives [44] of out-of-plane displacements (curvature and twist). Fig. 4 shows a non-destructive evaluation of a specimen subjected to thermal loading using a holo-shear lens as a shearing device.

With this brief history, it would not be out of place to point out that several commercial systems are currently available in the market, such as: (i) TV Holography/Shearography from Karl Stetson Associates [45] and (ii) 3D-ESPI/Shearography system from Dr. Ettemeyer Gmbh [46–48]. The potential of ESPI has been demonstrated and evaluated in real-world measurements and non-destructive evaluation. Novel applications of ESPI with pulsed or multiple laser sources [49,50], fiber-based optical head, high-resolution CCD cameras, and faster, efficient and robust algorithms continue to be published, thus testifying to the vitality of the technique. It is, therefore, reasonable to expect that in the coming years the DSPI will find a widespread use in the fields of aerospace engineering, biological and medical sciences, and electronic and automotive industries.

In this special issue on DSPI, the contributed papers from the frontline research groups currently working in this field address some of the research topics cited above. The first paper from Davilla et al. *is* devoted to the measurement of sub-

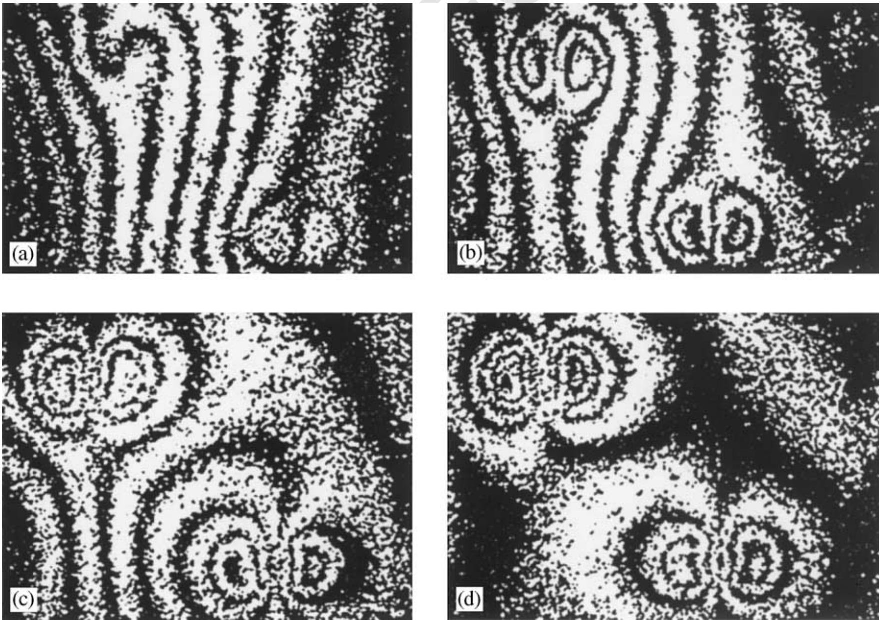

Fig. 4. Non-destructive testing of a specimen subjected to thermal loading.

surface delaminations in carbon fiber composites using high-speed phase shifted speckle interferometry and temporal phase unwrapping. Chen illustrates practical applications of ESPI in the automotive industry in the second paper. A prominent novel application involving the use of flexible fiber endoscope to approach hidden surfaces in biological and mechanical specimens is presented by Pedrini et al. The next paper by Aswendt and Schmidt reports on a method for characterizing the mechanical properties of micro-electro-mechanical systems (MEMS). Gren proposes the recording of transient events of the type of the propagation of bending waves from impacted plates using a multiple pulse interferometric arrangement. An and Carlsson discuss a method for the measurement of continuous phase changes due to object deformation. Falldorf et al. study the experimental feasibility of low coherence speckle shearography using a multiband light source. Ng reports on the use of diffractive optical elements as a cost-effective solution. The paper by Rao et al. presents some examples of non-destructive evaluation of spacecraft structural components. The issue completes with a paper by two Sciammarella's who describe the use of Heisenberg principle for fringe analysis.

The issue offers the state-of-the-art and takes a look towards trends of developments taking place in DSPI. The authors present in this special issue continue to make significant contributions to the field. We would like to use this opportunity to thank each of them and the referees personally for their efforts.

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