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Low cost simple laser speckle interferometer for deformation measurement

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Abstract

A novel technique of speckle photography has been applied to measure small deformation of a surface. A low-cost, commercial charge coupled device photo camera provides the images of speckle pattern through the beam splitter. Initially, a speckle pattern has been taken with the system at rest, and then second image captured after the deformation was made in the surface. By simple subtraction of the digital pictures, we obtain a fringe pattern that gives us information about the deformation.

Key words: Speckle interfrometry, non-destructive testing, deformation, phase difference, fringe pattern.

I. Introduction

For a long time, the speckle phenomenon was considered as a simple noise in imaging. However, speckle is a phenomenon which directly rises from the interaction of coherent light and medium. Therefore, speckle pattern is related to the medium properties, hence physicists took an interest in the exploitation of the speckle and several applications have been developed. Speckle metrology, a simple and widely used non-destructive evolution tool in metrology[1], is used in surface deformation analysis under mechanical or thermal loading conditions and determination of in plane translation[2]. Speckle interferometry is used to measure the deformation of micro electromechanical systems[3,4]. Other applications range from medical studies on bone dynamics to quality inspection of various products[5] and the measurement of the refractive index of a liquid in a cell was reported[6]. The most important ones are based on liquid penetrant, ultrasound, magnetic particle, eddy current, acoustic emission, radiology, active thermography and optical methods[7]. When an optically rough surface is illuminated with a coherent beam, a high contrast granular structure, known as speckle pattern is formed in the space is known as objective speckle pattern. It can also be observed at the image plane of a lens and it is then referred as subjective speckle pattern. The scattering regions are statistically independent and uniformly distributed between $-\pi$ and π. The speckles in the pattern undergo both positional and intensity changes when the object is deformed. The randomly coded pattern that carries the information about the object deformation provided to develop a wide range of methods, which can be classified into three broad categories: speckle photography, speckle interferometry and speckle shear interferometry. Speckle photography includes all those techniques where positional changes of the speckles are monitored, whereas speckle interferometry includes methods that are based on the measurement of phase changes and hence intensity changes. If instead of phase change, we measure its gradient, the technique falls into the category of speckle shear interferometry. All these techniques can be performed using digital/electronic detection using a CCD and imaging processing system. Illumination of a rough surface with coherent light produces a random intensity distribution in front of the surface, called speckle pattern[8]. Because of speckle pattern follows the movement of the scattering surface the speckle can be used for displacement or deformation measurement[9]. Beam division and combination can be analysis on the basis of either by amplitude (Michelson, Fizeau, Mach-Zehnder and Jamin mehtods) or by wave front division (Young and Fresnel-biprism) methods.

II. *Speckle Interferometry :*

In speckle interferometry, the object is illuminated with a coherent light source and the image of the object is recorded before and after the deformation or displacement. The optical setup for speckle interferometry is based on the Michelson interferometer[10]. The pattern that results by imaging a rough surface with a lens is itself a speckle field. The minimum size ρ_s of the image speckles is related to the optical system f-number F and the magnification M, and is given by :

$$\rho_s = 1.2(1+M)\lambda F \quad (1)$$

Where λ is the wavelength of the laser, and ρ_s is the radius of the Airy disc that is formed for the given optical imaging configuration[8]. The resultant intensity of each point of the object before deformation is given by:

$$I_{before} = I_{obj} + I_{ref} + 2\sqrt{I_{obj}}\sqrt{I_{ref}}\cos(\varphi_0) \quad (2)$$

where I_{obj} and I_{ref} are the local intensities of the object and reference beams respectively and φ_0 is the unknown, and random, initial phase distribution of the speckle pattern at that point.

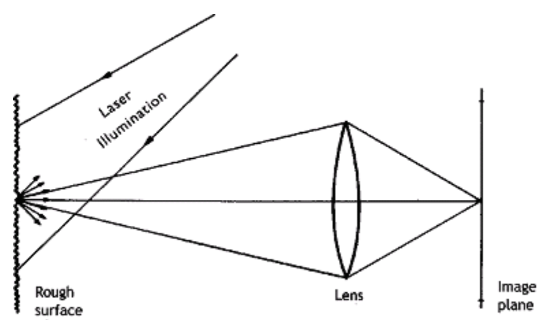


Figure 1. Basic for Speckle image formation

When the object moves, the phase distribution undergoes a change and the intensity at the object becomes:

$$I_{after} = I_{obj} + I_{ref} + 2\sqrt{I_{obj}}\sqrt{I_{ref}} \cos(\varphi_0 + \varphi_{obj}) \quad (3)$$

where $\Delta\varphi_{obj}$ is the phase change induced by object deformation, which is directly related to the out-of-plane displacement of the object according to the sensitivity vector theory:

$$u_z = \Delta\varphi_{obj} / 2\pi \cdot \lambda / (1 + \cos\theta i) \quad (4)$$

where λ is the wavelength used and θi is the incidence angle. From equation (3) it is possible to determine the displacement, once $\Delta\varphi_{obj}$ is known. A simple approach to measure $\Delta\varphi_{obj}$ is to record I_{before} and I_{after} and to calculate the difference:

$$\Delta I = I_{after} - I_{before} = 2\sqrt{I_{obj}}\sqrt{I_{ref}} [\cos(\varphi_0 + \Delta\varphi_{obj}) - \cos\varphi_0] \quad (5)$$

which can be rewritten as:

$$\Delta I = 4\sqrt{I_{obj}}\sqrt{I_{ref}} \sin\{ \varphi 0 + \Delta\varphi_{obj} / 2 \} \sin \Delta\varphi_{obj} / 2 \quad (6)$$

The intensity change ΔI depends on the random initial phase distribution φ_0 as well as on the deformation induced phase change $\Delta\varphi_{obj}$, therefore a statistical consideration is required to find a unique relationship between intensity change ΔI and phase change $\Delta\varphi obj$ during deformation[10].

III **Experimental setup**

The optical setup for speckle interferometry is based on the Michelson interferometer[11]. In the experiment, the interested object is a rectangular aluminum plate with a size of 220 mm and 165 mm. The light source is a 5-mW laser diode at the wavelength 680 nm. Such sources are commonly available as pointers or pattern projectors and provide a coherence length of a few centimeters, which is enough for our configuration. A lens is used to increase the laser divergence so that a significant portion of the target surfaces is illuminated.

The beam splitter divides the laser beam into two parts, each of which illuminates a different surface. The beam splitter also serves to combine the light diffused by the two surfaces. An image forming optical system, for example a converging lens is used to collect the diffused light and project the image onto a screen. For these conditions there are two overlapping images of the diffusing surfaces on the screen, each being a speckle field. Because the scattering angle is typically wide, such surfaces do not need to be exactly aligned. We used a polished glass plate with partial metal coating on one face as a beam splitter. Laser speckle interferograms of deformation on the aluminum plate are obtained before and after deformation. The subtraction cancels out the speckle grains that are unchanged leaving a dark area in their place. Overall a noisy bright fringe pattern that appears shows the area displaced by odd multiples of $\lambda/4$.contigious fringes differ by integer, it means by a step displacement of $\lambda/2$.

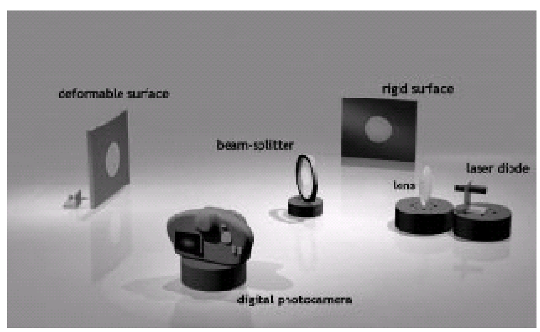


Figure. 2 Schematic set up of Laser Speckle Interferometer

IV **Result and Analysis**

The fringe decoding provides the information of deformation. To image the surfaces and detect the speckles, we used a CCD photo camera, adjusting its operation. The major requirement is that most of the speckle grains are resolved, that is, their size exceeds that of the camera pixels so we must adjust the speckles[12]. Strain gauges and extensometers available to determine the small deformation, but they are not suitable in all environment with accurate measurements. After the treatment by digital image correlation by Moiré's software, the results are obtained which are satisfied with other conventional measurement methods.

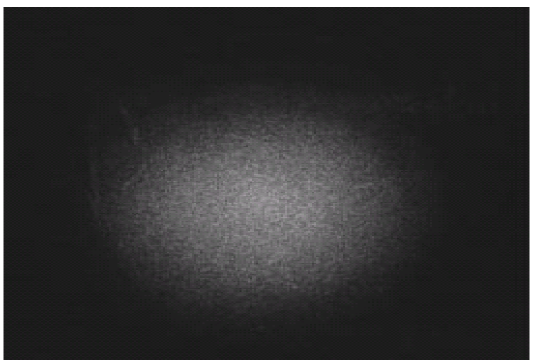
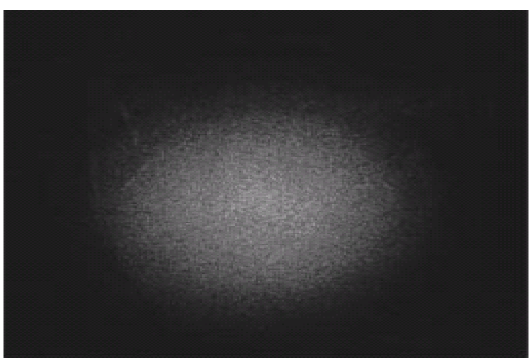
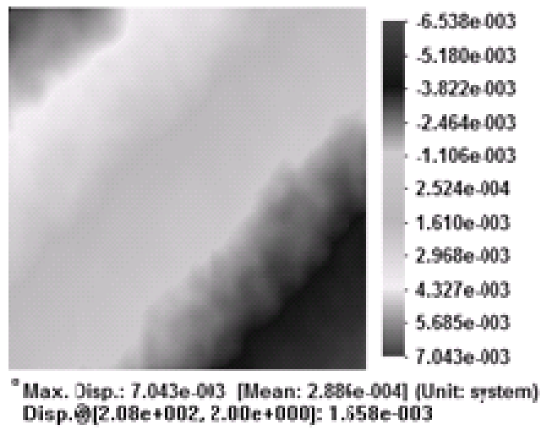


Figure 3(a) Before deformation



(b) After deformation

c) Subtracted image



d) Moiré's software for measurement

V. **Conclusion**

In this paper, double exposure Laser speckle photography experiment to detect small deformation of an aluminum plate has been done. The process to obtain fringes of the speckle pattern is simple and low cost. With computer assisted data analysis, precise information on the deformation can be obtained. The measurements are matching with other conventional gauge methods without much deviation. The current approach is non contact technique seems to be a powerful and simple solution to aggressive, hot, corrosive environments or very soft solids where gauges are not adapted accuracy.

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