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Phase Shifting Technique in Laser Speckle Image Processing

R.Balamurugan

Dept.of Physics,

KumaraguruCollege of Tecnology,

Coimbatore-641049. India.

E-mail: balamurugan.r.sci@kct.ac.in

Abstract— A simple technique of speckle photography has been applied to measure small changes/deformation of the surface of laser scattering materials. Low-cost commercial charge coupled device photo camera provides the images of Laser speckle pattern with the beam splitter arrangement. A speckle pattern has been taken with the system at rest and then second image captured after the deformation was made in the surface of the material. By simple subtraction of the digital pictures a fringe pattern obtained called as specklegram; it gives information about modification of the position of surface of the material.

Keywords— Laser speckle; subtraction of speckle images; Phase shift; fringe pattern; CCD Camera; image processing; deformation.

INTRODUCTION

Quick measurement of surface shape and deformation of mechanical parts of various materials is the ardent need of industries. Experimental methods in solid mechanics highly depend on surface displacement measurements. The conventional instruments cannot be used for those of soft materials and complex shape. Scanning method of mechanical probes takes much time hence it is not suited for quick and in-process measurement. Interferometry techniques are free from these issues have been mainly applied to optically smooth surfaces of materials. 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' as shown in Fig.1. It can also be observed at the image plane of a lens and it is then referred as 'subjective speckle pattern' as shown in Fig.2. 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 the speckle pattern follows the movement of the scattering surface the speckle can be used for displacement/deformation measurement [9]. Beam division and combination can be analysis on the basis of either by amplitude (Michelson, Fizeau, Mach-Zehnder and Jamin) or by wave front division (Young and Fresnel- biprism) methods.

SPECKLE INTERFEROMETRY

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 ρs of the image speckles is related to the optical system f-number F and the magnification M, and is given by: $\rho_s = 1.2(1+M)\,\lambda F$ ... (1)

Where λ is the wavelength of the laser, and ρs is the radius of the Airy disc that is formed for the given optical imaging configuration. The resultant intensity of each point of the object before deformation is given by: $I_{before} = I_{obj} + I_{ref} + 2\sqrt{I_{obj}}\sqrt{I_{ref}}\cos(\varphi_0)$ … (2)

where, I_{obj} and I_{ref} are the local intensities of the object and reference beams respectively and φ0 is the unknown, and random, initial phase distribution of the speckle pattern at that point.

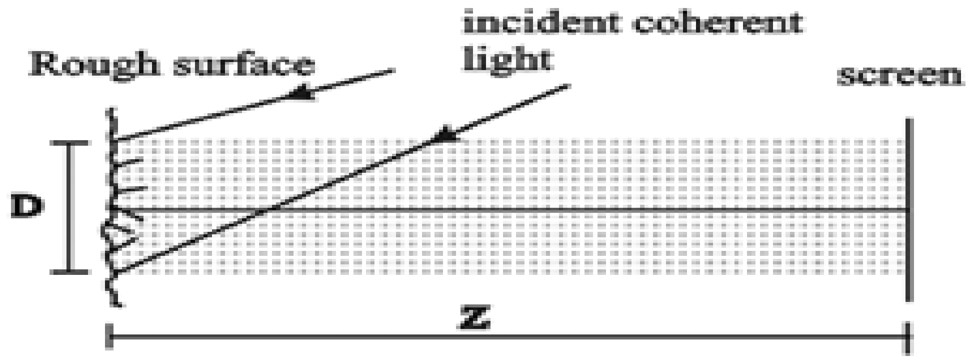

Fig.1 Basic for Speckle image formation
(Objective type)

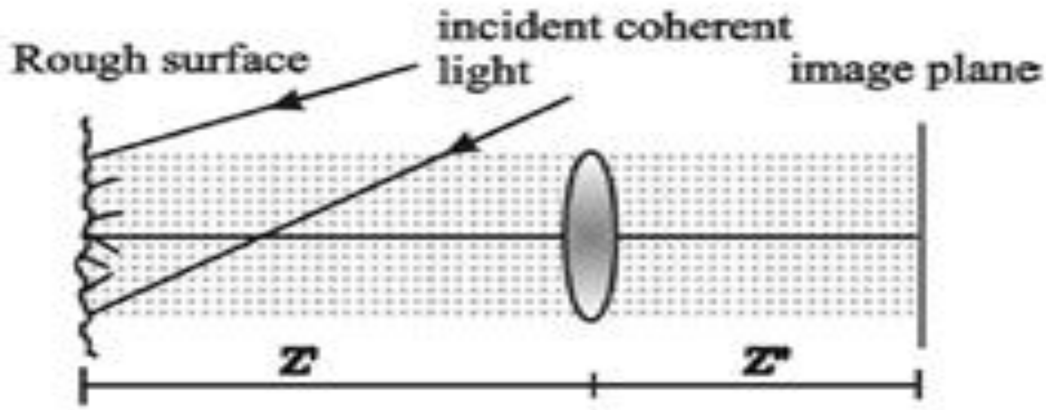

Fig.2. Basic for Speckle image formation
(Subjective type)

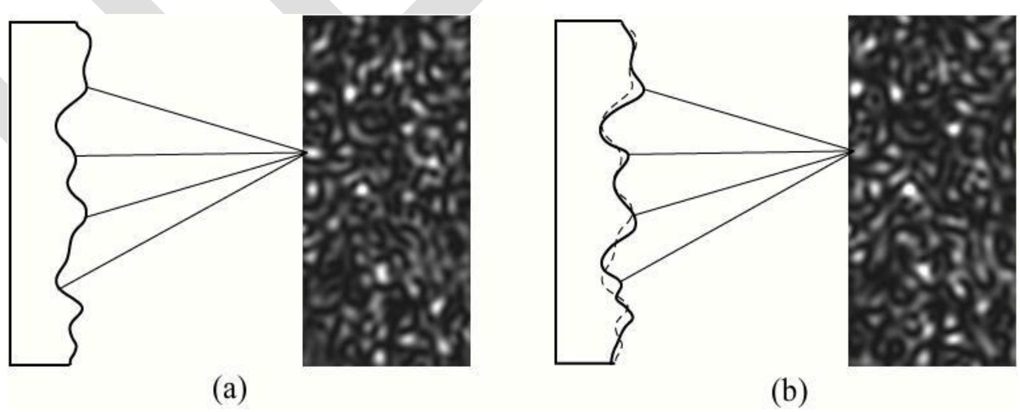

Fig.3. Basics for Speckle image formation (a) Basic Speckle pattern formation (b) changes in the microstructure of the surface (The original surface is indicated by the dashed line)

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

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

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

where λ is the wavelength used and θ_i 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 is:

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

which can be rewritten as:

$\Delta I = 4\sqrt{I_{obj}}\sqrt{I_{ref}} \sin\{ \varphi_0 + \Delta\varphi_{obj}/2\} \sin \Delta\varphi_{obj} /2$ ... (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.

EXPERIMENTAL SETUP

It basically uses a setup analogous to a Michelson interferometer in which both mirrors are replaced by scatter surfaces. The resultant speckle pattern in the image plane is formed by the interference of the two speckle fields issuing independently from the two scatter surfaces. One of the surfaces is subjected to deformation and the other serves as the source of reference speckles [11]. The resultant speckle pattern in the image plane is formed by the interference of the two speckle fields issuing independently from the two scatter surfaces. One of the surfaces is subjected to deformation and the other serves as the source of reference speckles [11].

The interested object is a rectangular mild steel carbon plate with a size of 220 mm and 165 mm. The light source is a 5-mW laser diode at the wavelength 630 nm. 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.

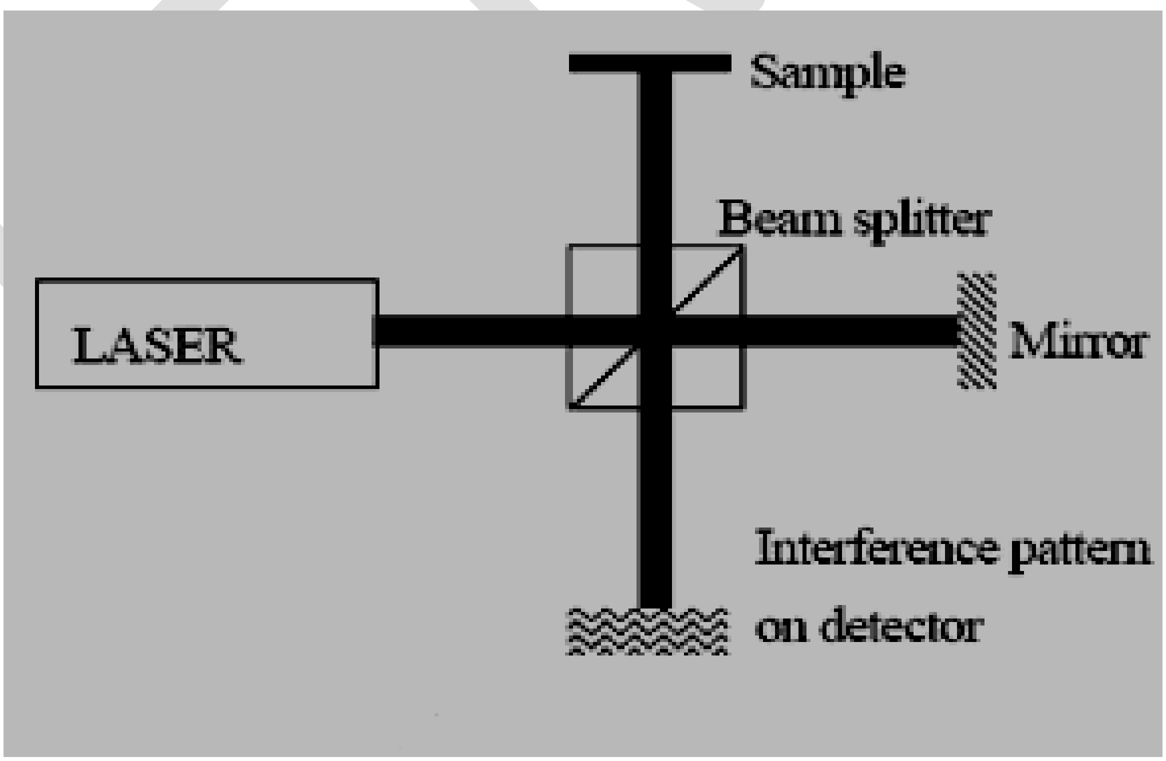

Fig.4. Basic model interferometer

RESULT AND ANALYSIS

Laser speckle interferograms of deformation on the mild steel carbon plate are obtained before and after deformation.

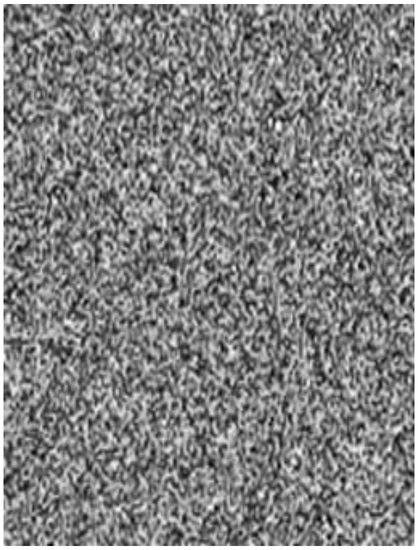

Fig.5. Speckle- after deformation

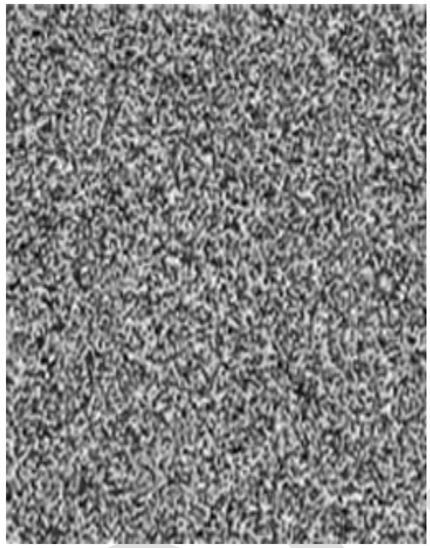

Fig.6. Speckle- after deformation

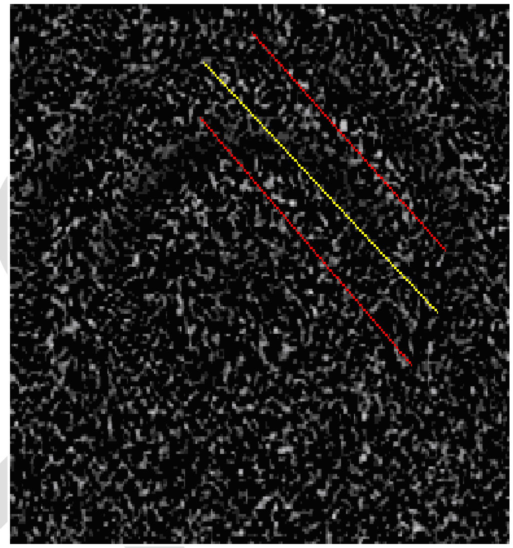

Fig.7. Fringe pattern – Subtracted

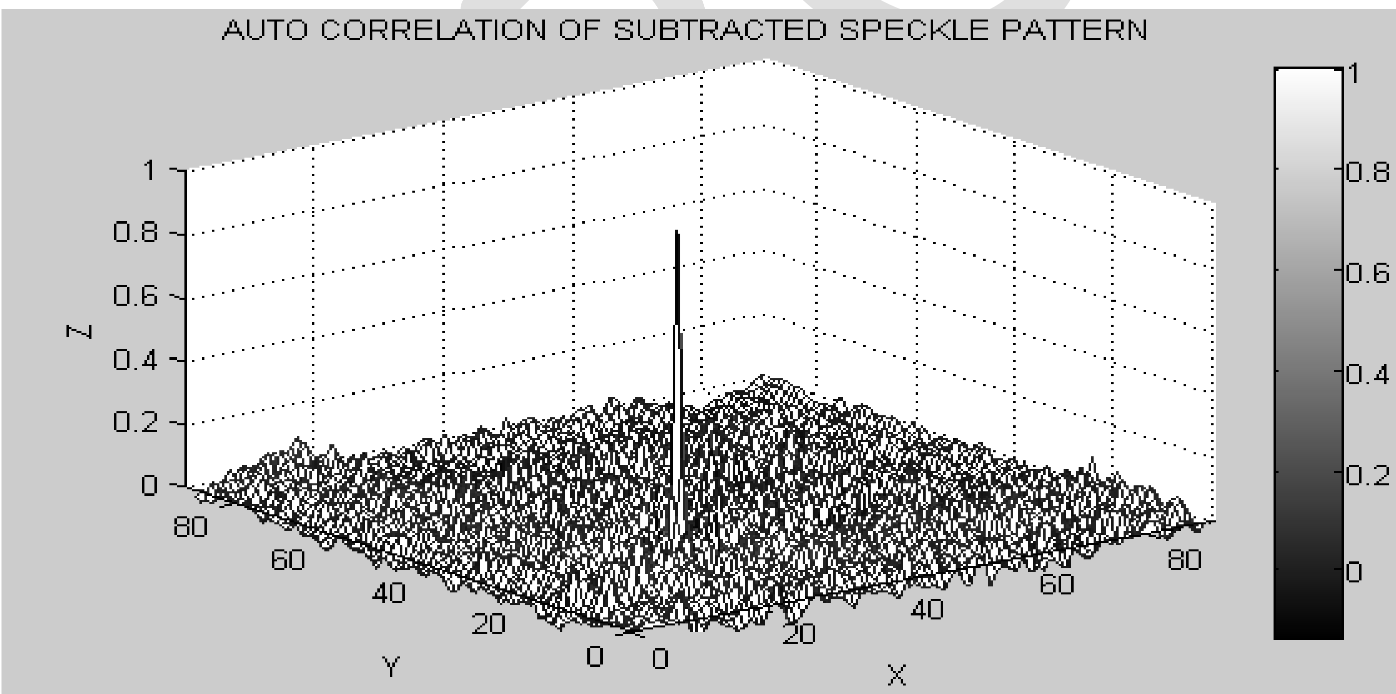

Fig.8. Peak value of deformation

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 $\lambda/2$. Now 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]. To find the deformation by the fringe analysis method and two red lines are drawn to be tangent to the centre of two adjacent fringes.

The yellow line is drawn to pass through the centre of one of the fringes where it intersects the edge of the test piece. The distance between the two red lines is the width of one fringe which we call "X"(here measured to be 5.01 in arbitrary units) and the distance from the centre of the lower fringe to the yellow line we have called "Y" (here measured as 1.44). The flatness of the test piece is then: Y/X = 1.44/5.01 = 0.282. Hence this value (0.282x2=0.564) equal to 0.6µm displacement/deformation shown in MATLAB. Strain gauges and extensometers available to determine the small deformation, but they are not suitable in all environment with accurate measurements.

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CONCLUSION

In this paper, a simple double exposure electronic speckle photography technique to detect small deformation of mild steel carbon plate has been done. Speckle displacement is detected from the position of correlation peak. Its results agree well those obtained from the conventional methods. The components for this work are typically inexpensive and the image processing of the laser speckle pattern is simple. Digital correlation analysis of speckle patterns arising from coherent optical systems is used effectively for non contact and non destructive measurements by means of low cost photonic device and digital technology.

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