Laser Speckle Image Processing

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Abstract: In this paper, Electronic laser speckle correlation technique has been adopted to measure small deformation of a specimen. A Low cost Opto-electronic Laser Speckle Interferometer is designed. Laser speckle images are captured ahead of the deformation stage and next in the deformation stage. Subtraction of these two digital speckle records, a fringe pattern called as Specklegram is obtained. This gives information about the deformation and results are verified by conventional gauge methods.

Keywords: Optical sensor, Laser speckle Interferometer, image processing.

I. INTRODUCTION

It is the ardent need of industries to estimate the surface roughness, dimension and deformation of mechanical components of different materials. The traditional instruments cannot be suitable for the soft materials and complex dimenension components. Due to the time consuming concept the Scanning mechanical probes technique is not well-matched for quick and in-process measurement. Speckle interferometry [1] is a very good option for non-contact, high-accuracy and full-area measurements in industry. A speckle image is formed, when an object with an optically rough surface (approximately 0.6micron in most of the materials) is shed light on with a highly coherent source of light such as laser. Before the invention of laser it was considered that, speckles were a nuisance and has to be suppressed or eliminated. However, now become an important subject of optical metrology for full-field Non destructive Testing.

The speckle techniques can be classified broadly as speckle photography, speckle interferometry and speckle shear interferometry. Speckle photography [2] includes the methods where positional changes of the speckle are monitored. Speckle interferometry [3] based on the principle of measurement of phase changes. Suppose, instead of the phase change, gradient measurements are considered then the method falls into the category of speckle shear interferometry or shearography [4]. The new developments in the area of electronic detection techniques give the impetus to the research area of Speckle Pattern Interferometry (ESPI) or TV Holography [5]. Full-field laser Non Destructive Evaluation method is based on interferometry in the optical science field. This paper is structured as follows: Details of laser speckle, then design and development of optical sensor, finally measurement of displacement using image correlation technique.

Laser speckle

If an optically rough surface is illuminated by a coherent source of light, then it will be scattered back from every illuminated object point as shown in Fig.1.

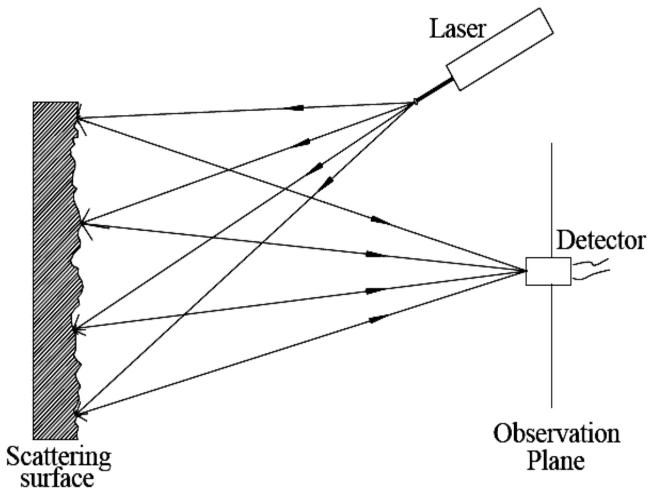

Figure.1 Basics for Speckle image formation

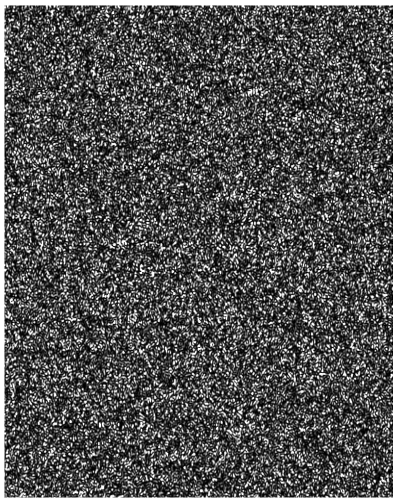

Figure.2. Speckle pattern

When the cold finish stainless steel 303 annealed specimen is viewed by a high resolution camera, the surface of the specimen seems to be covered with bright and dark spots, called as speckles. These speckles result from the path differences of the light emitted by the laser and reflected to the aperture of the imaging system. Coherent light like laser is incident on rough surface having height variations more than the wavelength of the light, then it is scattered form a pattern with of dark and bright spots called as speckles shown in Fig.2. The interference phenomenon is the reason for this cigar like speckles. This phenomenon is called the speckle effect. In white light, speckle effect is difficult to observe because of incoherence. The speckle pattern characterized by a random intensity and phase distribution and is basically a statistical process and scattering regions are statistically independent and uniformly distributed between $-\pi$ and π [6]. The intensity pursues a negative exponential distribution. If the statistical properties of the speckle pattern are determined by the size of the illuminated spot, the pattern is called objective. As a replacement, the statistical properties of the speckle pattern are determined by the aperture of the lens arrangement, the pattern is called subjective.

II. METHODS AND MATERIALS

Development of laser speckle interferometry is a modification of Michelson interferometer, described by R.Balamurugan, S.Muruganand [7]. Instead of mirrors M1and M2 in the Michelson interferometer, we use thin sheets of plates (diffuse scatterers), which are having optical roughness. In the experimental setup, the specimen is a stainless steel 303 annealed specimen plate and the source is a 5-mW laser diode of wavelength 680 nm. Such sources are available as low cost pointers and provide a coherence length of a few centimeters. Most of the commercial laser interferometers set the reference plate near the beam splitter so that alignment is easier and the measurement is more robust to environmental changes. Moreover, the scattering angle is typically wide so the surfaces need not be aligned exactly. The experimental setup is shown in (Fig.3)

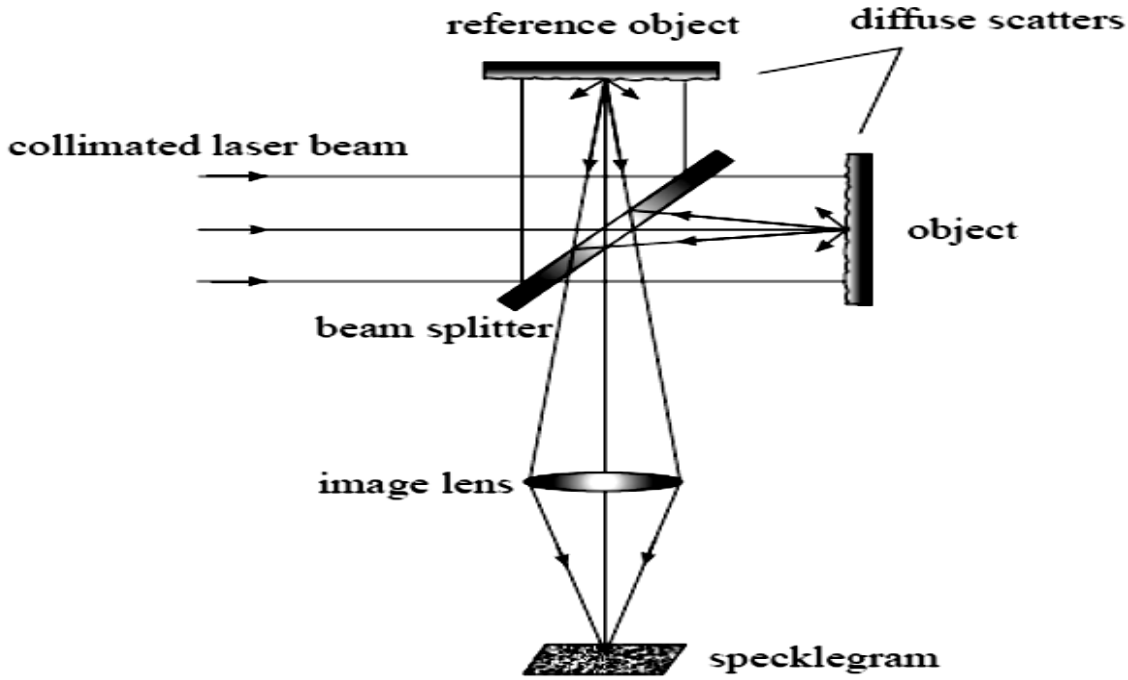

Fig.3.Modified form of Michelson Interferometer (Experimental setup)

We induced a deformation in a surface by pushing along the center portion in the X plane for attaining deformation, with the help of mechanical tip (screw gauge) on its rear side. Position of the camera, is adjusted in such a way that to focus on one scattering surface through the beam splitter. Since the optical paths of the two surfaces are the same overlapping images focused automatically.

A CCD photo camera with resolution: 2048X1536 pixels used to detect the speckle images. To maximize the speckle size we have to choose the maximum magnification M and F, the maximum f –number of the photo camera. The operation is easier if the plates are rigidly tolerating the vibrations caused by environmental factors. To avoid vibrations we could link the camera to a personal computer and take pictures with a keyboard command without touching the camera.

III. RESULTS AND DISCUSSION

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 as:

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

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. The intensity of each point of the object before deformation is given based on the description in the paper [8]:

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

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

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

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. Images of speckle pattern Fig. 4(a),4(b) and specklegram 4(c) shown below:

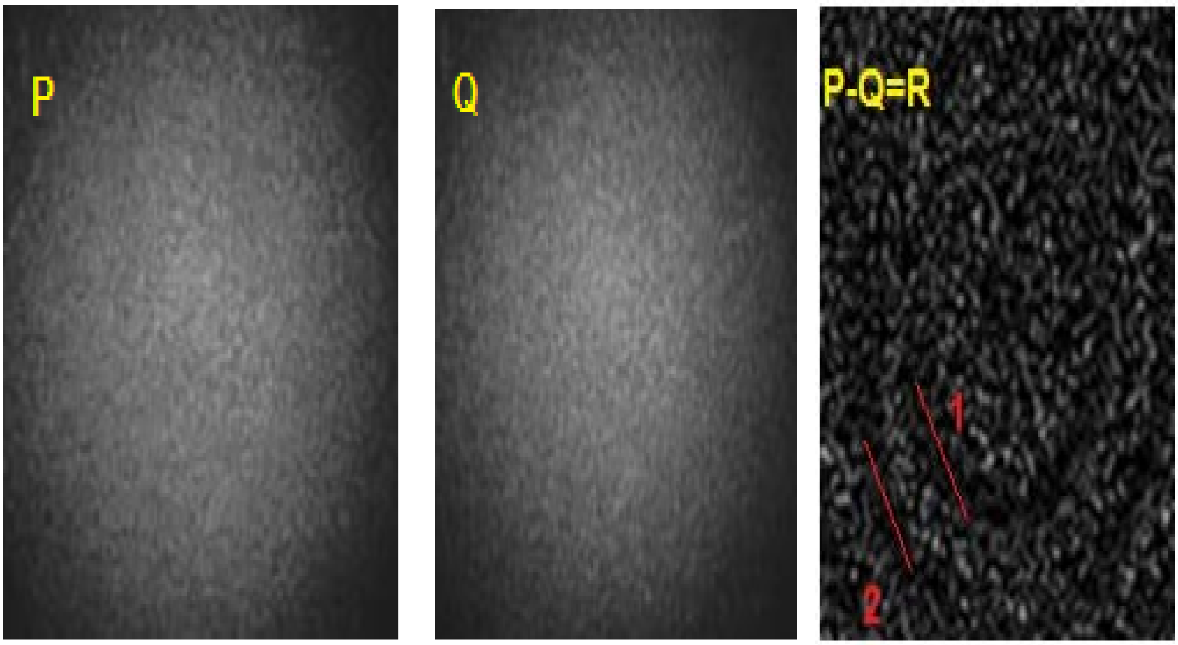

Fig.4(a) Before deformation Fig.4(b) After deformation Fig.4(c) specklegram

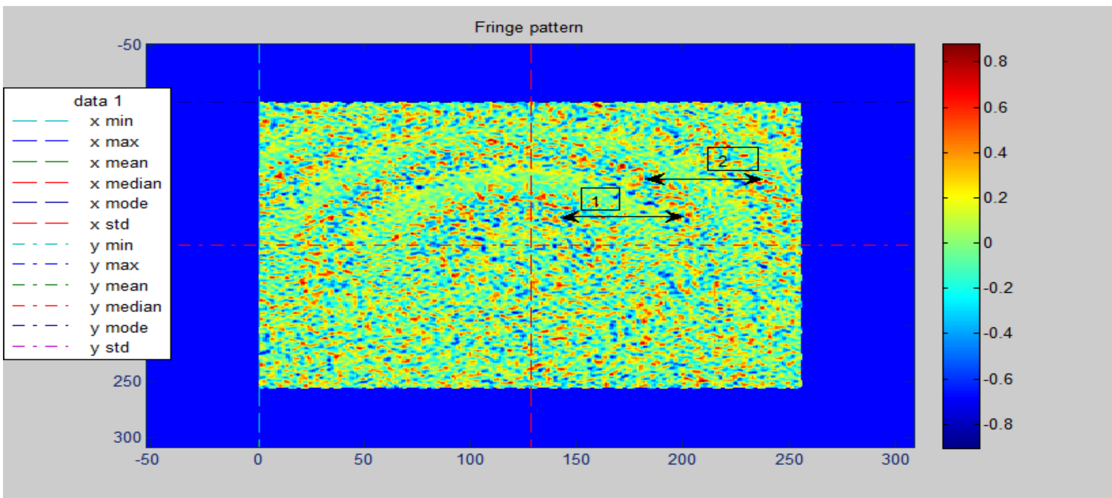

Fig.5. Analysis of subtracted speckle image (specklegram) with Matlab

After the treatment by digital image processing by MATLAB software, the results are obtained which are satisfied with other types of conventional gauge methods. By conventional calculation of fringe counting method we know the distance between the two fringes equal to $\lambda/2$. From the subtracted speckle image, we get two fringes and hence 2 x ($\lambda/2$) = λ = 680nm (Red colour diode laser). In terms of micron, displacement/deformation value is 0.680 micron which is nearly equal to 0.7 micron. This result is satisfied with the speckle image technique, which gives 0.8 micron. To minimize the error, we have to provide suitable vibration isolation table arrangement and interfacing camera to a personal computer to take pictures with a keyboard command without touching the camera and all other corrections to be taken for environmental factors which are affecting the setup.

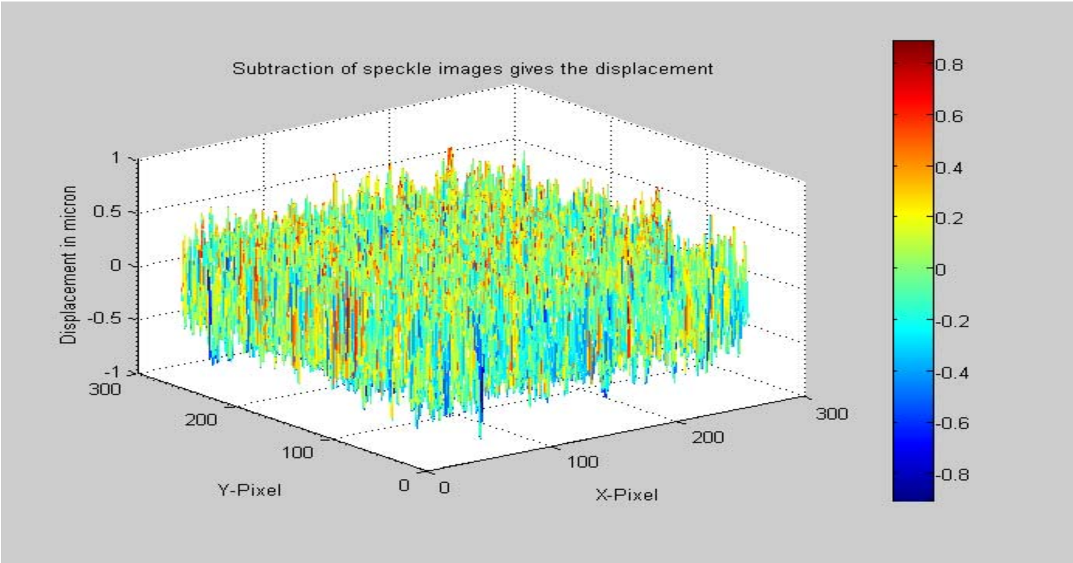

Fig.6. Measurement of Deformation/Displacement value (0.8micron)

IV. CONCLUSIONS

In this paper, a non-contact optical sensor with speckle imaging technique has been developed for the detection of small deformation of a stainless steel 303 annealed specimen. Optical components for this work are typically inexpensive. The processing of the speckle pattern to obtain fringes is simple.

ACKNOWLEDGEMENTS

The author would like to thank the management of Kumaraguru College of Technology for the continuous support for doing this work.

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