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APPLICATION OF A PHOTOPOLYMER MATERIAL IN SPECKLE PATTERN SHEARING INTERFEROMETRY

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ABSTRACT

A new application of a photopolymer diffractive optical element in electronic speckle pattern shearing interferometer (ESPSI) is presented. In the first stage a holographic grating is recorded using an acrylamide based photopolymer material. Since the polymerisation process occurs during recording, the holograms are produced without any development or processing. In the second stage the holographic grating is used to produce the two sheared images in an ESPSI configuration. A ground glass screen following the grating serves the purpose of eliminating unwanted diffraction orders. The distance between the grating and the ground glass can be used to control the amount of the shear. The sheared images on the ground glass are further imaged onto a CCD camera. The proposed system is simple and flexible.

1. INTRODUCTION

1.1. Electronic speckle pattern shearing interferometry

Electronic speckle pattern interferometry (ESPI) can only directly measure displacement. Electronic speckle pattern shearing interferometry (ESPSI) enables direct measurements of displacement derivatives to be made. In ESPSI two images of the object are formed on the camera faceplate, one of which is slightly shifted laterally, i.e. sheared, with respect to the other. In effect the reference wave in conventional ESPI is replaced by a shifted object wave. The frame grabber captures this double image. After loading the object a second double image is subtracted from the first to produce a pattern of fringes which are contours of the spatial gradient of the displacement with respect to surface coordinates [1]. The sensitivity of the interferometric system depends on the amount of shear that is introduced between the images.

1.2. ESPSI using diffraction gratings

The idea of using a holographic grating for shearing of the two images in speckle shearing interferometry is not new. Iwahashi et al. [2] described a speckle shearing interferometer using a single grating recorded on holographic plate. The grating was placed in front of the image plane at a distance 0.95 mm from it and the amount of the shear was 0.55 mm. A photosensitive plate located in the image plane was exposed to the sheared images before and after deformation. Fringes are obtained by spatially filtering light transmitted by the plate. Joenathan & Sirohi [3] described a speckle shearing interferometer also using a single grating recorded on holographic plate. The grating was placed in front of the image plane at a distance of 2.3 mm from it and the amount of the shear was 1.07 mm. Again a double-exposure specklegram (before and after the loading) was recorded. In both papers [2, 3] a photographic plate was used for recording the fringe patterns. More recently electronic versions of a speckle shearing interferometer using holographic gratings were reported. Rabal et al. [4] presented an ESPSI system using a single grating placed directly in front of the CCD camera. The grating was a holographic phase grating with a spacing of 8 lines per mm. The grating frequency has to be low in order for the pitch of the grating to be resolved by the CCD camera This limitation is essential for the ESPSI system because most ordinary CCD cameras will not resolve gratings with spacing greater than about 50 lines per mm. Joenathan & Bürkle [5] demonstrated a ESPSI system using a unit consisting of a single grating and a ground glass in front of the CCD camera. However they did not present experimental results with this system.

ESPSI using a diffraction grating as a shearing element is an attractive alternative to other shearographic systems [2, 3] using gratings as it provides observation of real-time fringe formation and the possibility of phase-stepping analysis. The ESPSI system presented by Joenathan & Bürkle [5] is of interest for further development as the introduction of the ground glass removes the limitation for the grating frequency to be low.

We suggest a new application of a photopolymer holographic grating in ESPSI.

1.3. Photopolymer recording material

Self-processing acrylamide based photopolymer [6] is used as a recording medium for recording holographic gratings.
The photopolymerizable polymer layer consists of the following:

- Green sensitive dye (erythrosin B) for use at 532 nm.
- Triethanolamine (electron donor)
- Acrylamide and ethylene bisacrylmide (monomer mixture)
- Polyvinyl alcohol binder

When the dry layer is illuminated with the appropriate wavelength of light the dye molecule absorbs the incident photon energy and is excited to the triplet state. The excited dye molecule reacts with the electron donor to produce free radicals. The free radicals interact with acrylamide monomer and thus free radical polymerization is initiated. The changes in density and molecular polarizability, which accompany polymerization, cause a change in local refractive index. Thus the material can be used for recording phase holograms.

The optimized photopolymer material gives good diffraction efficiencies up to 94% for an exposure of 80mJ/cm^2 and it performs well in the transmission mode of hologram recording.

2. EXPERIMENT

The arrangement of the electronic speckle pattern shearing interferometric system with a single photopolymer holographic grating is presented schematically in Figure 1. A laser diode, with wavelength 785 nm and a maximum output power of 50 mW, is used as the light source. A laser beam illuminates the object at an angle to the normal to the object surface. A lens images the object onto a ground glass. A holographic photopolymer diffraction grating is placed in front of the ground glass which acts as a diffusing screen. The spatial frequency of the holographic grating is 500 lines per mm. The diffraction efficiency of the grating is 60%. The distance between the grating and the ground glass is *d*.

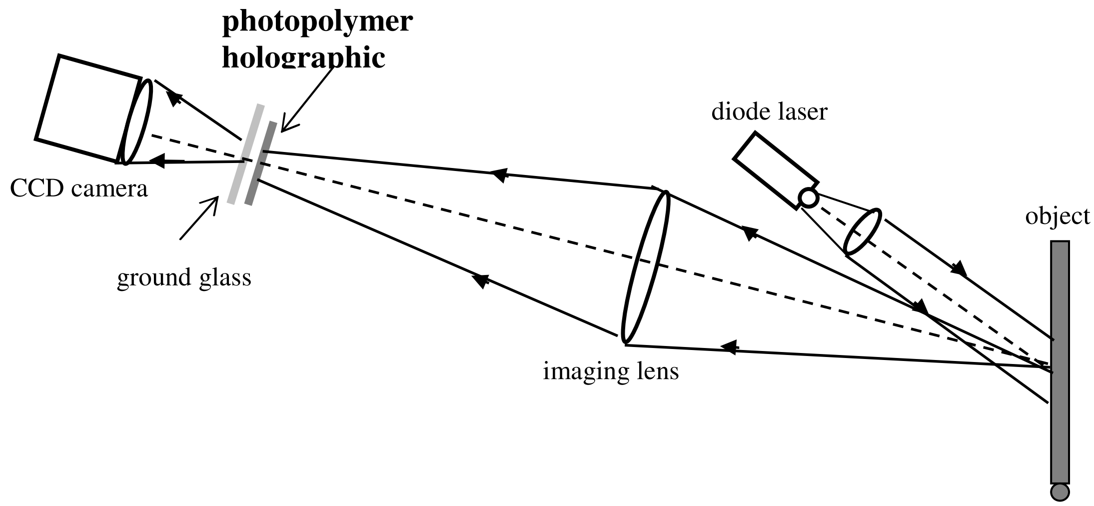

Fig.1. An optical set-up of the ESPSI system with a photopolymer grating

The shear Δx between the two images on the ground glass depends on the distance *d*, the angle of the incident light on the grating ψ, and the angle of the diffraction of the first order θ [5]:

$$\Delta x = d[\tan\psi - \tan(\theta - \psi)] \tag{1}$$

The unit consisted of the photopolymer grating and the ground glass is tilted with respect of the optical axis of the imaging lens until the two sheared images of equal intensity are obtained. The sheared images are imaged by a second lens on a CCD camera and displayed on a monitor (Fig. 2).

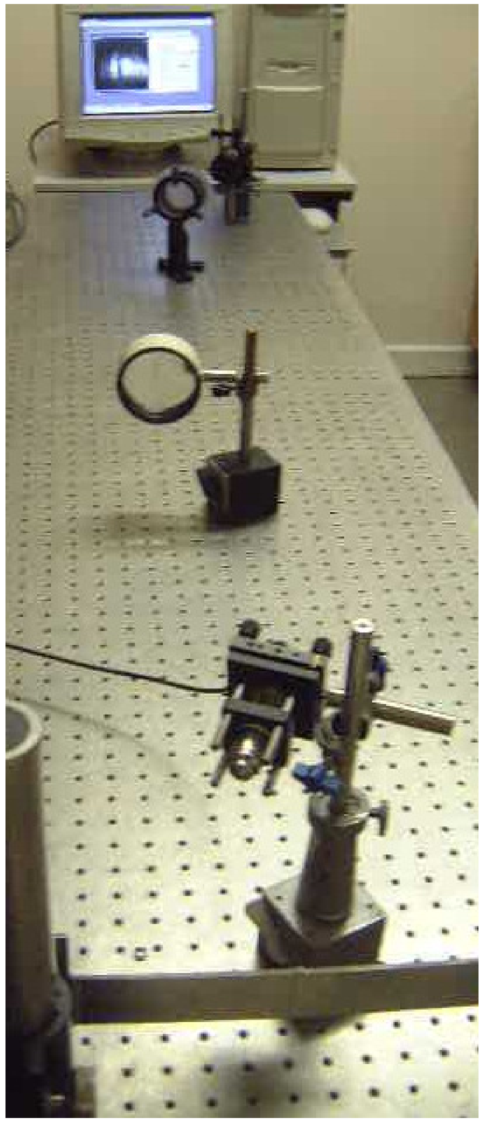

Fig. 2. Experimental set-up of the ESPSI system with a photopolymer grating

The sample is a 3 mm thick metal cantilever fixed at one end. The other end is deflected in steps of 5 μm.

3. RESULTS AND DISCUSSION

Figure 3 shows the results from the test of the ESPSI system using a photopolymer holographic grating to introduce the shear. Fringe patterns were recorded using 3 mm thick metal cantilever clamped at the end. The other end was deflected in steps of 5 μm. The deformation force applied was normal to the cantilever. When the cantilever is deformed, the corresponding speckle pattern is subtracted from the initial speckle pattern, stored in computer memory. The fringe pattern characteristic of the derivative of the displacement of the deformed object is displaced on the computer monitor. The fringe patterns obtained show consistency and reproducibility. A filter with a 3x3 window was used to remove the speckle noise in the images.

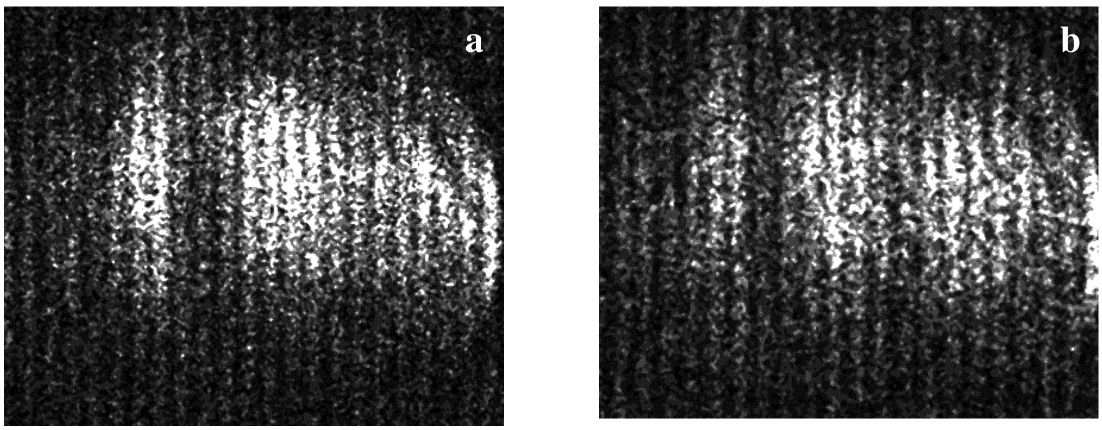

Fig. 3. ESPSI fringes in metal cantilever fixed at one end. The other end is deflected by: a) 15 μm; b) 20 μm;

The quality of the ESPSI fringes recorded is poor. However, as far as we know, this is the first report of experimental results which demonstrates the concept of ESPSI with one holographic grating developed by Joenathan & Bürkle [5]. Further work will be done for improving the contrast of the fringe patterns.

4. CONCLUSIONS

A new application of a photopolymer diffractive optical element in electronic speckle pattern shearing interferometer (ESPSI) is presented. In the first stage a holographic grating is recorded using an acrylamide based photopolymer material. Since the polymerisation process occurs during recording, the holograms are produced without any development or processing. In the second stage the holographic grating is used in an ESPSI configuration. The holographic grating is used to shear the two images on a sheet of ground glass. The distance between the grating and the ground glass can be used to control the amount of the shear. The sheared images on the ground glass are further imaged onto a CCD camera. The introduction of the ground glass in the ESPSI system removes the limitation for the grating spatial frequency to be low in order to be resolved by the CCD camera. The ESPSI system using a diffraction grating as a shearing element has some advantages compared to the commercially available systems based on a combination of a beam splitter and two mirrors (modified Michelson interferometer). It is compact, offers a simple way to introduce discrete phase steps between two images by changing the distance between the grating and the imaging plane. An additional advantage is the low cost of such a system.

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