A THESIS

ENTITLED

STUDIES ON INTERFERENCE OF SCATTERED COHERENT WAVES

Presented By

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ARABIC SUMMARY

General Introduction

The appearance on the scientific scene of the laser in the early nineteen sixties set off many new lines of research in the field of Physical Optics, which had previously been felt unprofitable to explore further. Interferometry was an obvious choice, since the greatly enhanced brightness and coherence of laser sources makes the experimentation much easier than when conventional light is used.

Speckle interferometry offers a new way of performing high-sensitivity measurements on objects not having a specularly reflecting surface. In this sence it strongly parallels hologram interferometry, but without the complication of the intermediate holographic process. Laser speckle photography have no counterpart in conventional interferometry, nevertheless it depends upon the interference effects producing the speckles. All the techniques that have been developed show that the laser speckle effect, far from being a hindrance to the optical research worker, has become the means of "finger printing" an optically rough surface so that its positional behaviour can be closely followed with wavelength sensitivity, without the need to disturb the surface by touching or making it in any way.

In chapter I laser photographs which are double-exposed before and after a displacement of diffusing objects are studied. In-plane surface displacement and axial one are measured. Double photography consists of identical speckle patterns displaced relative to each other. The displacement can be easily determined from the Young's interference fringes in the spectrum of the photograph.

Two visibility curves for lateral and axial translations are obtained. These curves facilitate the measurement of any translation for diffusing objects by measuring their visibility only.

Chapter II deals with the production of interference fringes that represent the intersections of a three dimensional object by a set of equally spaced virtually plane surfaces. Contouring fringes resulting from double photography reveal the topography of the object (cylinder, sphere and two plane perpendicular surfaces) like the level lines of a map. The lines of the levels for a diffused object are defined relative to the conjugate plane of the photographic plate in the object medium. The fringes indicate some information of the form of the illuminated surface.

RECORDING OF IN-PLANE AND LONGITUDINAL DISPLACEMENT BY DOUBLE EXPOSURE SPECKLE PHOTOGRAPHY

CHAPTER I

I.1- Introduction

The random intensity distribution which is now termed a speckle pattern is formed when fairly coherent light is either reflected from a rough surface or propagates through a medium with random refractive index fluctuations. Such patterns are clearly visible even to the casual observer when highly coherent laser light is used. In general the statistical properties of speckle patterns depend both on the coherence of the incident light and the detailed properties of the random surface or medium, although for perfectly coherent light this dependence on the random scatterer is almost negligible if the scatterer introduces path differences greater than one wavelength.

At the present time interest in speckle patterns lies in approximately six main areas :

a- fundamental statistical properties.

b- reduction of speckle in optical and holographic systems.

c- measurement of surface roughness.

d- applications in image processing.

e- applications in metrology, and

f- stellar speckle interferometry.

Chapter I is dealing with applications in metrology. The technique is therefore limited to the measurement of very small displacements unless the speckle size is made large. For the case in which the imaged speckle does translate by more than a speckle diameter, correlation methods can still be used.

By setting up a camera and recording photograph of an object, illuminated from any arbitrary direction by laser light, displacement of its surface in any direction orthogonal to the line of sight may be readily measured.

Double exposure photographs are taken on fine-grain plates or film, before and after the movement. The two speckle patterns recorded will be locally identical, but displaced by an amount and in a direction related to the movement of the corresponding part of the surface. While in some instances it might be possible to measure the displacement by identifying corresponding speckles on the two images, this is more readily done by examining the diffraction pattern of the recorded speckle intensity distribution.

Analysis of a double exposure photograph is carried out by directing a narrow beam of light, conveniently from a laser, on to the film record and measuring the spacing and direction of the diffraction fringes. In this way a point - by - point record of the variation of speckle pattern separation, both in magnitude and direction, can be built up. It is possible to achieve an accuracy of at least 0.1 μ m using this method.

I.2- Previous Work

Burch and Tokarski[1], described a method for producing interference fringes equivalent to those produced by a series of linearly arranged pinholes without actually constructing such pinholes.

Exposures of varying duration were recorded on a photographic plate which was successively displaced with respect to a laser speckle pattern. The Fourier transform of the pattern produced by these multiple exposures was then obtained optically by illuminating the plate with converging spherical waves. The fringes observed were similar to those occuring in multiple beam hologram interferometry.

By multiple equal exposures it means that the plate is given equal displacements in between exposures.

An expression similar to the interference pattern from a set of $(N + 1)$ identical equidistant pinholes of equal transmission could be derived. Ten exposures were made.

When the number of displacement increased, the fringes become considerably sharper and the number of intermediate maxima increased. The exposures in the ratio of the binomial coefficients are made and the plate is again given equal displacements in between exposures, then the intermediate maxima vanish and the fringes are broader than that of the same exposure. Leendertz[2] described another method for detecting a small displacement of the order of a few wavelengths by making a single exposure and using the negative as a filter. The surface was illuminated with two coherent light fields of random phase and amplitude. The fact that if two speckle patterns are super imposed, the distribution of intensity in the resultant pattern depends on the relative phases of the component patterns and by measuring the correlation between the resultant patterns at two different times and accordingly a change of relative phase is detected, leads to a versatile method of measuring either the normal or in-plane components of displacement over the whole of a surface at one time.

The speckle patterns falling on the plate were linearly polarized to optimize fringe contrast. Light from helium-neon laser at λ (6328 Å) was used throughout. Archbold et al[3] have been measured much larger displacement of the order of a few tens of microns by making two successive exposures and then filtering the negative. The transition between the two above methods appears when the displacement in the image plane is of the same order of magnitude as the size of the diffraction spot of the imaging lens.

They used uni-direction illuminated object, so the in-plane displacement can be measured from the observed Young's fringes to obtain fringes of good contrast.

They reached up to 50% visibility in the final fringe pattern. The coarseness of the speckles which were recorded depends upon the numerical aperture of the lens which focus an image of the object. Experimentally, they found that fringe contrast increases with density. The resolving power of the emulsion used plays a very important factor for its relation with speckle size and the F number of camera lens.

The number of the fringes observed was proportional to the longification and inversely proportional to the numerical aperture of the lens. In order to obtain good contrast, a bleaching solution (such as Kodak R10) could be used, and a suitable spatial filtering system must be used for obtaining more uniform level of brightness. Another method of viewing fringe patterns in highly dense photographic recordings is to examine the light reflected by the surface of the emulsion. Greater dispacements than this, however, can be measured by observing the optical transform of the doubly exposed recording of the image .

In this case the effect no longer relies upon the non-linearity of the recording medium, and a single direction of illumination only is required. Archbold and Ennos[4] have indicated a very simple method in which a single laser beam is used to illuminate the object. Surface displacement can be measured by recording a double-exposure photography, followed by optical processing of the recorded speckle-pattern image. The analysis can either be on a point-by-point basis using a small viewing aperture, or by spatial filtering technique which resolves the motion in any desired direction orthogonal to the line of sight. The film used to record the fine structure must then be sufficiently fine-grained to resolve the speckle size. A 35 mm camera using Agfa GEVAERT 10E 75 film was used. They found that there are many factors which effect the sensitivity of the experiment, such as :-

1) Imaging quality of the lens.
2) Aberrations particularly distortion.
3) The image movement between exposures is greater than one the speckle diameter.
4) The speckle patterns remain correlated with one another.

They found that the theoretical upper limit to the magnitude of the displacement, orthogonal to the line of sight, that can be measured is set by the fineness of the optical transform fringes that can be resolved this will depend upon the size of the recorded image that can be used to generate the fringes. The minimum theoretical displacement that can be measured will be about one sixth of the lateral dimension, independent of the magnification employed. They also derived an expression for calculating the radius of the produced circular fringes resulting from longitudinal displacement by double exposure technique and making a comparison of this formula with experimental measurement. Françon et al[5], used double-exposure technique for measuring the longitudinal displacement. They illuminated the object with a speckle pattern, thus the sensitivity of the technique could be increased. They proposed a double-exposure method in which the object is illuminated under a large angle of incidence (θ) by a random beam which is generated by laser-illuminated ground glass. After the first exposure, the object undergoes an axial translation ξ and the photographic plate is laterally displaced. Considering ξ is small and by assuming that this axial translation results only in a lateral displacement ξ tg θ of the incident amplitude from the ground glass. Under these conditions, the two intensity distributions recorded by the photographic plate are no more indentical and the contrast of the Young's fringes observed in the