LAMP/94/6

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

LAMP SERIES REPORT

(Laser, Atomic and Molecular Physics)

VISUALIZATION AND DIRECT COMPARISON OF LARGE DISPLACEMENTS USING DIFFERENCE HOLOGRAPHIC INTERFEROMETRY

F. Necati Ecevit

and

Ramazan Aydin

INTERNATIONAL ATOMIC ENERGY AGENCY

UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

MIRAMARE-TRIESTE

LAMP/94/6

International Atomic Energy Agency
and
United Nations Educational Scientific and Cultural Organization
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

LAMP SERIES REPORT
(Laser, Atomic and Molecular Physics)

VISUALIZATION AND DIRECT COMPARISON OF LARGE DISPLACEMENTS USING DIFFERENCE HOLOGRAPHIC INTERFEROMETRY

F. Necati Ecevit
Department of Physics, Middle East Technical University,
06531 Ankara, Turkey

and

Ramazan Aydin [1]
International Centre for Theoretical Physics, Trieste, Italy.

ABSTRACT

The difference holographic interferometry provides the possibility of direct comparison of large displacements and deformations of two similar but different objects by application of a special kind of illumination. In this work, the principles of the difference holographic interferometry are described and the experimental results obtained by applying the single beam technique to large displacements is presented.

MIRAMARE – TRIESTE

September 1994

[1]Permanent address: Department of Physics, Middle East Technical University, 06531 Ankara, Turkey.

Preface

The ICTP-LAMP reports consist of manuscripts relevant to seminars and discussions held at ICTP in the field of Laser, Atomic and Molecular Physics (LAMP).

These reports aim at informing LAMP researchers on the activity carried out at ICTP in their field of interest, with the specific purpose of stimulating scientific contacts and collaboration of physicists from Third World Countries.

If you are interested in receiving additional information on the Laser and Optical Fibre activities at ICTP, kindly contact Professor Gallieno Denardo, ICTP.

ICTP LASER GROUP
P.O. BOX 586
34100 Trieste
Italy
Phone: +39+40+2240322
Fax: +39+40+224559
email: ***passarel@ictp.trieste.it***

1. Introduction

The holographic interferometry enables us to study objects of irregular shape and even rough objects that reflect diffusely. It is only necessary that the microstructure of the object should not change appreciably when the object passes from one state to another. Changes such as deformation, displacement or even a change of refractive index of the object will affect the appearance of the interference pattern observed, since these changes result in phase distortions of the wave it scatters.

The usual holographic interferometric techniques such as real-time and double-exposure interferometry offer the possibility of displacement measurements of objects but do not allow their direct comparison. To compare them, the interferograms of the individual objects are evaluated and only then calculated data can be compared numerically. On the other side, due to the high sensitivity of holographic interferometry large displacements having unresolvable

interference pattern cannot be investigated by conventional holographic techniques.

The difference holographic interferometry (DHI), called also comparative holography, provides the possibility for the direct holographic comparison of two objects by using a special kind of object illumination. In the DHI, the object to be investigated called test object is illuminated with the holographically reconstructed real image of a master object serving as the base of comparison. The test object is illuminated in its initial state with the initial image of the master object and in its final state with the final image of the master object. The interferogram produced in this way displays directly the difference only. The main feature of DHI is that holographically recorded waves are used for illumination by wavefront reversal which enables applications also to large displacement measurements.

The true idea of DHI was proposed by Neumann in 1980 [1]. Prior to this, the principle was realized by Denby at al [2] by using electronic speckle pattern interferometer in 1976.

The DHI has been applied successfully on a wide range of holographic interferometric measurements of diffusely reflecting and transparent objects [3-6]. More details concerning the principles of DHI are also given in [7-8].

Direct holographic comparison of different objects have been demonstrated by using conjugate picosecond pulses by Abramson [9]. He proposed a new contouring method that is based on sending picosecond laser pulses toward a test object in a such sequence that if the object has the wanted shape all the scattered light arrives simultaneously at a detector. The result is that the shortness of the detected pulse is a measure of the likeness between a holographically recorded master object and the test object.

2. Principle of the Method

In the DHI two coherent wave fields with phase difference are produced in a proper way. First, the recording and developing process of the master object are carried out in usual way by double-exposure technique. Second, using the conjugate real wave fronts of the master hologram for illumination, a double-exposure interferogram of the test object is recorded. The phase difference between the master wave fronts is given by

$$\Delta\Phi = (\vec{k}_2 - \vec{k}_1) \cdot \vec{L} \tag{1}$$

where $\vec{k}_1$ and $\vec{k}_2$ represent the illumination and observation vectors with $|\vec{k}| = 2\pi/\lambda$, respectively, and $\vec{L}$ gives the displacement vector at the object surface point considered, as shown schematically in Fig. 1.

Likewise the phase difference between the test wave fronts of the test hologram is written as

$$\Delta\Phi' = [(-\vec{k}_1) - (\vec{k}_2)] \cdot \vec{L'} \tag{2}$$

where $-\vec{k}_2$ and $-\vec{k}_1$ are illumination and observation vectors, respectively, and $\vec{L'}$ is the displacement vector of the test object.

The difference of the displacements $\vec{L}$ and $\vec{L'}$ is obtained from Eq. (1) and (2) as

$$\Delta\Phi_- = \Delta\Phi' - \Delta\Phi = (\vec{k}_2 - \vec{k}_1) \cdot (\vec{L'} - \vec{L}) \tag{3}$$

which corresponds to an illumination of master wave fronts in original sequence. Using illuminating master wave fronts in reversed sequence, the sum of displacements $\vec{L}$ and $\vec{L'}$ results in

$$\Delta\Phi_+ = \Delta\Phi' + \Delta\Phi = (\vec{k}_2 - \vec{k}_1) \cdot (\vec{L'} + \vec{L}) \tag{4}$$

Thus, both the difference as well as the sum of the interferograms of the master and test objects can be recorded.

3. Experimental Verification

The optical setup used in the experiments is illustrated in Fig. 2, where beam expanding elements are not shown. The laser beams illuminating the object and the holographic plate are widened by diverging lenses. The arrangement is composed mainly of two parts: the first part indicated by solid lines is used for recording master holograms while the second part (broken lines) served for recording the difference interferometric fringe systems.

Laser beam from the argon-ion laser (Spectra Physics Model 2020-05) is divided into two parts. The beam passing through the beam splitters BS1, BS2, and BS3 and directed by the mirror M1 onto holographic plate HP is served as the reference beam for recording the master hologram. The beam reflected from the mirror M2 illuminates the master object O (solid lines).

The object used as master as well as test object was a plate of brass mounted on a rigid body by three screws and a spring so that the surface of the plate to be investigated could be moved in three dimensions. The object could also be painted to achieve different states.

A double-exposure interferogram was made in the usual way by changing the position of the object surface between two exposures. Fig. 3 shows a typical interferogram with small displacements produced by this method. Then the developed hologram was placed in its original position accurately by means of the auxiliary beam coming from BS2. In the next step the master object O was replaced by the test object O', which was done by painting the object O by a spray paint to simulate the different but similar object. A new double-exposure interferogram concerning the object O' was recorded on the holographic plate HP' using the reference beam coming from the beam splitter BS3 and the object wave fronts reversed by the mirror M'. The position of the object from approximately the same initial value was changed to an arbitrary one. The holograms were developed in the usual processing technique described, e.g., in [10]. As hologram recording material we used Agfa-Gevaert 8E56 HD NAH plates in thickness of 3.3 mm, whose holographic characteristics meet a considerable number of serious requirements for this specific application [10].

The interferometric fringes belonging to the test object and the difference are shown in Fig. 4.

4. Results and Discussion

This work demonstrates that large displacements produced on surfaces of rigid bodies can be made visible by DHI and studied in optical accuracy. If displacements of the master object and of the test object may be so large that their interferometric fringe systems too dense to be observed, the difference interference pattern will be visible. The photographs of the test and the difference interferograms are shown in Fig. 4. The interference pattern belonging to the test object (upper part of Fig.4) is unresolvable due to the large displacements of the object while the difference one is resolved and visible (lower part).

Reconstructing the difference interferogram, interferences of four wavefronts can be observed. These are the difference interference pattern and other disturbing interferometric fringe systems corresponding to the sum of the displacements. The latter causes a decrease in contrast of the difference interference pattern. The influence of this effect can be minimized or even eliminated from the interferogram by proper choice of the loads for the test and

master objects. Another critical point of the experiment is that the optical alignment of the conjugate beam for illumination the test object surface needs very careful replacement of the master hologram in its place after development. This was achieved by means of an auxiliary beam (the beam from beam splitter BS2 in Fig. 2).

As is well known, the coherent properties of the light source determine the visibility of the fringe pattern and consequently the quality of the recorded hologram. On the other side, the amount of the light scattered by the object on the recording plane is a function of its size and shape. The maximum area which can be viewed with a single hologram is governed basically by the amount of the laser power available. In this work, the demand on radiated power was a few watts at single frequency operation. To meet this requirement and obtain a high contrast interference we employed an argon ion laser equipped with a temperature controlled Fabry-Perot etalon (Spectra Physics Model 583), which delivers a single mode beam with a sufficient coherence length resulting in a good quality fringe pattern.

Acknowledgments

This work was partially supported by the Scientific and Technology Research Council of Turkey and the Research Fund of the Middle East Technical University. One of the authors (R.A.) would like to thank Professor Abdus Salam, the International Atomic Energy Agency and UNESCO for hospitality at the International Centre for Theoretical Physics, Trieste, and for the award of associate Fellowship.

References

[1] Neumann D.B., *Comparative holography*, Topical meeting on hologram interferometry and speckle metrology, Opt. Soc. Am. , pp. MB2-1 to MB2-4, 1980

[2] Denby D., Quintanilla G.E., and Butters J.N., *Contouring by electronic speckle pattern interferometry*, Proceeding of the Stratclyde Conference 1976, Cambridge University Press, pp. 323-349

[3] Gyimesi F. and Fuzessy Z. , *Opt. Commun.*, **53**, 1985, 17

[4] Neumann D.B. , *Opt. Eng.*, **24**, 1985, 625

[5] Fuzessy Z. and Gyimesi F. , *Opt. Commun.*, **57**, 1986, 31

[6] Fuzessy Z. and Gyimesi F. , and Banyasz I. , *Opt. Commun.*, **68**, 1988, 404

[7] Fuzessy Z. and Gyimesi F. , Opt. Eng. **23**, 1984, 780

[8] Gyimesi F., Fuzessy Z., *J. Modern Optics*, **35**, 1988, 1699

[9] Abramson N., *J. Opt. Soc. Am. A*, **9**, 1992, 1193

[10] Smith H.M. (ed.), *Holographic Recording Materials* , Springer- Verlag, Berlin, 1977

Figure Captions

Fig. 1. Schematic representation of formation of displacements in the master object. S_1 and S_2 are the initial and final positions of the object, where A and B indicate the positions of an object surface point before and after displacement.

Fig.2. Schematic diagram of the optical arrangement applied in recording and reconstruction of the holograms.

Fig.3. A typical double-exposure interferogram of the master object subjected to a poor loading.

Fig.4. Interferogram of the test object (upper part) and the difference interference pattern (lower part)

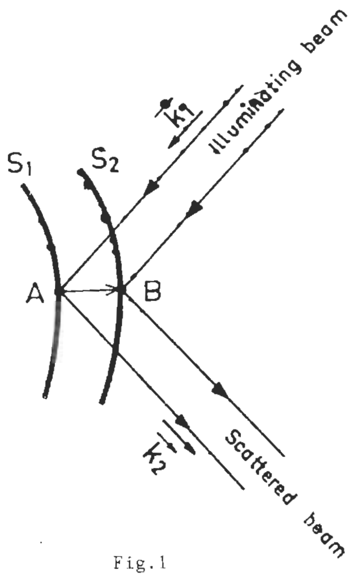

Fig.1

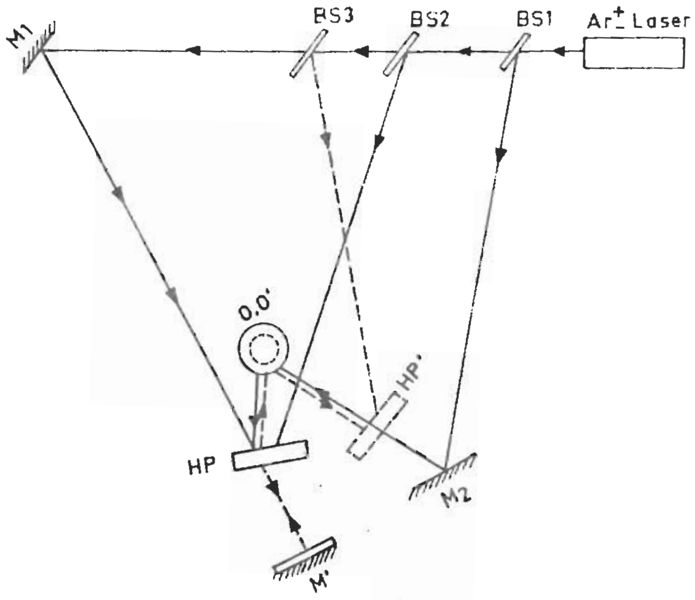

Fig.2

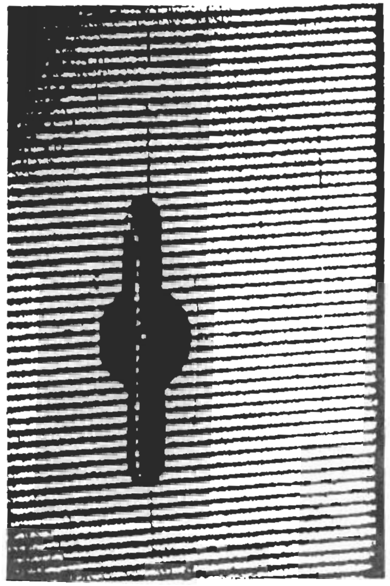

Fig.3

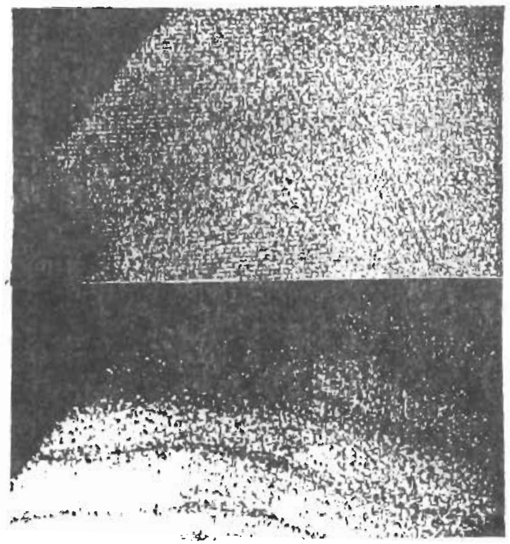

Fig.4