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HOLOGRAPHIC NON-DESTRUCTIVE TESTING OF MATERIALS USING PULSED LASERS +)

H. Fagot*, F. Albe*, P. Smigielski*, J.L. Arnaud**

* Institut Franco-Allemand de Recherches de Saint-Louis, 68301 Saint-Louis, France

** Société Nationale des Industries Aéronautiques et Spatiales, Laboratoire Central, Suresnes, France

Abstract

Double exposure holography with two monomode pulse ruby lasers is used with the double objective of detecting various defects in aircraft structures subjected to non-destructive shocks and of observing the behavior "in situ" of a few samples during fatigue testing.

I. Introduction

Interferometric holography permits to visualize slight deformations (of the order of a few µm) of large-size three-dimensional objects presenting arbitrary surface conditions. Toward this end an interferogram is taken by double exposure of the photographic plate. Between the two exposures the object, the defect of which is to be detected (these defects are often not visible on the surface), is subjected to particular stressing such as mechanical, pneumatic or thermal stressing. In the reconstruction process, a three-dimensional picture of the object is observed through the hologram. The deformations occurring under stressing are visualized as interference patterns localized in the vicinity of the image of the object surface. If at that place at which the defect exists, the object deformation differs from that observed in the neighboring regions without defect, the defect can be detected because the interference fringes exhibit a particular aspect. For the holographic non-destructive testing of materials it matters to choose a stressing technique which is not only adapted to the visualization of some specific defects in a given material, but which is also compatible with particular environment conditions (for instance laboratory or industrial environment).

Holography based on the use of CW-lasers turned out to be a valuable tool for the non-destructive testing of materials. A host of studies performed abroad and in France allowed this type of testing to be used in manufacturing processes (series production or developmental work). However the operating conditions involved (dark room, vibration-free arrangements, bulky and not dismountable optical tables) make the use of this method somewhat complicated in certain cases where it could be of great advantage. This applies especially to maintenance checks on aircraft and helicopters as well as to fatigue tests.

The use of pulsed ruby (or YAG) lasers permits to avoid the aforementioned restricting conditions. Very short exposure times (of approximately 20 ns) allow the use of a more simple set-up. Two pulses separated by a few µs produce a double-exposure hologram of the structure under investigation subjected to realistic dynamic stress (vibrations or mechanical shock loading). Well-known in this domain are the papers of ERF and co-authors published in the USA as well as the works of FELSKE and HAPPE in Hannover [1][2]. We shall report on experiments performed in laboratory as well as "in situ" in an industrial environment. The paper is divided into two sections. In the first section, a report is given on results obtained "in situ" on a fatigue testing machine installed at SNIAS near Paris (Suresnes). In the second section, one describes experiments conducted in laboratory at Saint-Louis with the objective of visualizing defects in aircraft elements (wing, panel) excited under the action of non-destructive shocks.

II. The Holographic Camera

A holographic camera was designed and built at ISL for fatigue testing. This holographic device includes two ruby lasers mounted on parallel benches (see Figure 1). Each laser is made of similar elements, that is three inches long oscillator rubies and six inches long amplifier rubies. Each laser delivers light pulses of 100 millijoules with a duration of 20 nanoseconds. Power supplies are not visible in the field of the picture.

Figure 2 shows the principle of double exposure performed with two ruby lasers. The time interval Δt separating the two exposures is adjustable at will from 0.1 µs to "infinity" ; τ is the delay of 1 ms or more between the trigger signal and the first laser pulse. It comprises the time necessary to the flashes for pumping the rubies and a dead time use-

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ful for adequate synchronization. The precise time is dependent on Pockels cells triggering.

It is also possible to trigger the lasers with respect to the phase of a periodical signal by adjusting the delays 1 and 2 (Figure 3). An automatic synchronization device permits interludes of several periods T by preselecting a number from 1 to 16. This can only be done with two ruby lasers for experiments at industrial frequencies, typically 100 Hz or less.

The beams emanating from laser 1 and laser 2 (Figure 4) are mixed with the aid of a mirror and a beam splitter. The holographic arrangement is identical with that used for single laser off-axis holography.

III. Tests Performed with a Fatigue Testing Machine

Fatigue tests have been conducted with a traction machine. Under the action of the machine, the test bar undergoes periodical traction constraints of the order of one ton at a frequency of nearly 100 Hz. Holograms were recorded without interrupting fatigue testing, the duration of which was several hours. The test bars were chosen because of their characteristics demonstrative of problems typically met in aeronautics. The test bar shown in Figure 5 is made of a composite material based on carbon fibers and pierced with a hole of 19 mm in diameter. Loosening of the layers around the hole can be seen during the fatigue test.

Typical results were obtained with a propagation test bar (Figure 6). It is a piece of light alloy used for studying the propagation of a crack originating from a notch. We observe fringes which may be at different degrees of inclination, discontinued along the crack. The region of plastic deformation appears on the photograph and more distinctly on the hologram itself. It was necessary to have a Δt of 0.5 ms or 1 ms for a good visualization of the deformation of this thick piece.

The influence of the synchronization is illustrated in Figure 7. An accelerometer placed on the test machine delivered a signal in phase with the traction applied to the test bar. The crack can be seen only when the variation of the stress is strong between the two exposures.

Another test bar was a riveted light alloy assembling. It is made of two metal sheets placed end to end and assembled with the aid of a third metal sheet riveted to them (Figure 8). Two records taken on a phase quadrature, with weak time lapses Δt, are significant of the complex movement of the assembling and of the effect of the rivets.

With Δt = 10 periods T, just before the rupture, the fissure is distinctly visible at the level of the first row of rivets (Figure 9).

IV. Tests Performed with Non-Destructive Shock Loading

In order to check aircraft structures such as honeycomb panels, assembled metal sheets, bonding of various materials, it is well-known that vibration tests allow to disclose anomalies. With the aid of continuous-wave lasers, it is possible to visualize the element under investigation using holographic interferometry, that is time average holographic interferometry, real time holographic interferometry, or double exposure holographic interferometry. In this case, resonant frequencies must be obtained by varying the excitation frequency. With pulsed lasers, it is more convenient to generate the excitation with a rapid shock which exhibits a whole succession of frequencies.

For our tests, an electromagnetic hammer was used with an electric energy of a few joules (Figure 10). The velocity of the core was of the order of a few meters per second. The contact bars had the double objective of delivering a synchronization signal and reducing the shock on the structure under investigation. The time delay τ is dependent on both the size and the nature of the sample. The field observed has a diameter of approximately 60 cm. The time interval Δt is adjusted as a function of both amplitude and frequency of the modes of vibration. It is of the order of 2 to 5 microseconds.

Figure 11 shows a hologram taken on a plate made of two foils in aluminium joint with adhesives to both sides of an aluminium honeycomb structure. Two structural defects were generated artificially : absence of honeycomb over a diameter of 3 cm and disbonding over a diameter of 10 cm. These two defects are clearly detected with aspects varying according to τ and Δt (Figure 12).

Under the same conditions, the element of an aircraft wing of 40 cm in width was tested. This wing element is the wall of a fuel tank. It is made of sheets joint with adhesives and riveted and reinforced with two longitudinal frames and several transversal frames (Figure 13). The closely succeeding modes of vibration reflect the rigid structure of the element. This is true if there is a good adherence between the various components or if there is a liquid in contact with the wall such that the vibrations are damped. In Figure 14 the modes of vibration have a quite different aspect. Here the adherence is rather poor with the liquid absent. The disbonded longitudinal frame does no longer appear as a band of weak deformations.

V. Concluding Remarks

The examples given above show pulsed-laser holography to be a strong candidate for first detection and rapid localization in situ of anomalies present in aircraft structures. This method is particularly suitable for detecting defective bonding, as well in maintenance as during fabrication. It is also convenient for detecting cracks during fatigue testing. It is expected to become a useful complementary tool for methods based for instance on the use of X-rays and ultrasonics.

References

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Holographic Non-Destructive Testing.
Academic Press, 1974.

[2] FELSKE, A., HAPPE, A.
Double pulsed holography as a diagnostic method in the automotive industry.
In : The Engineering Uses of Coherent Optics, edited by Robertson E.R., Cambridge University Press, 1976, 595-614.

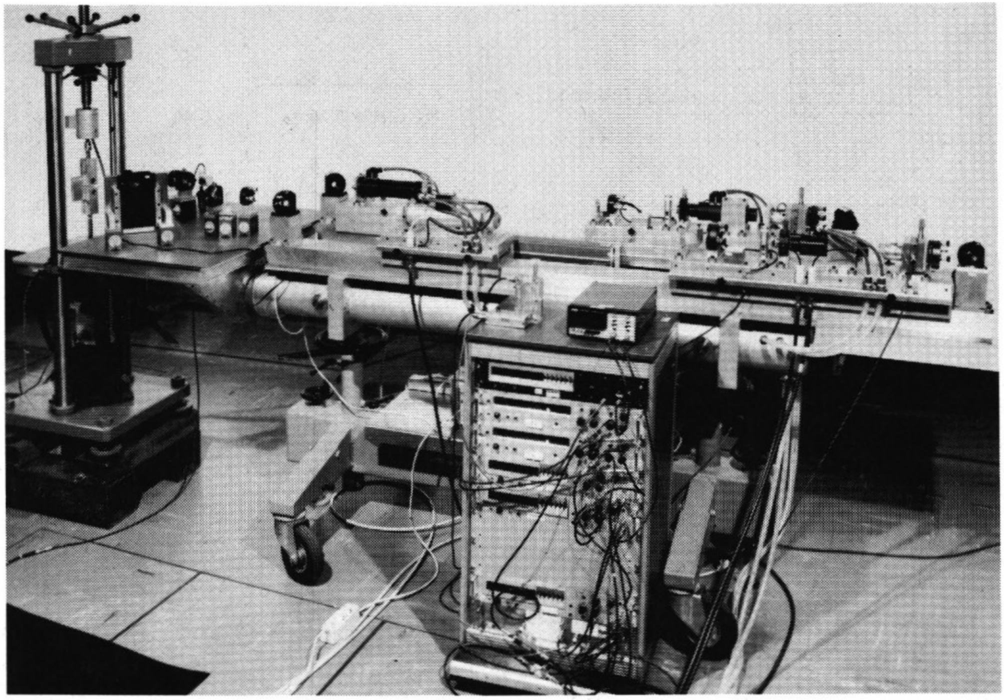


Figure 1. General view of the camera built at ISL for holographic interferometry with two pulsed lasers

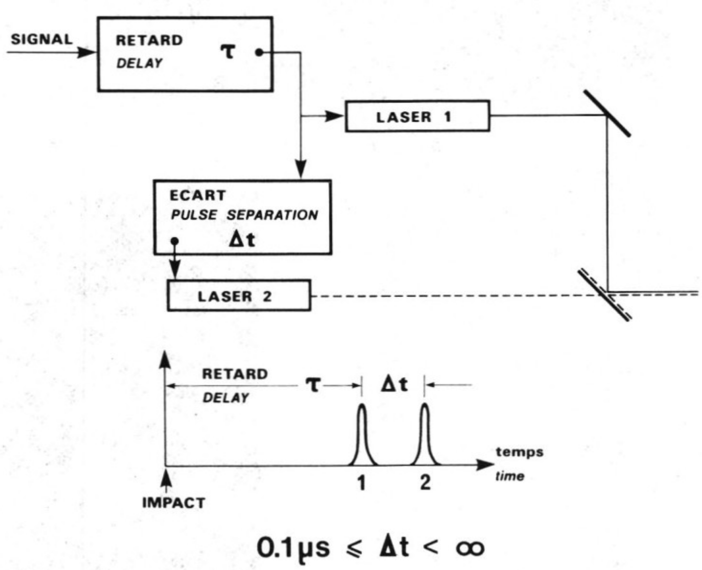


Figure 2. Double exposure with two lasers

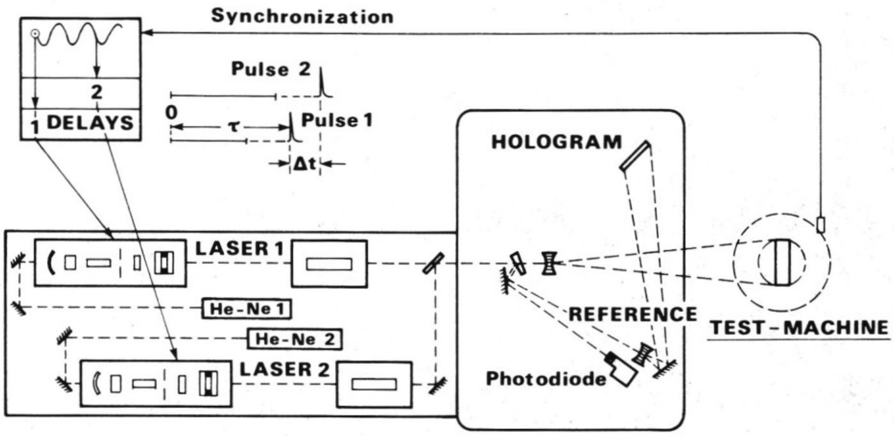


Figure 3. Schematic diagram of holographic experiment on a fatigue testing machine

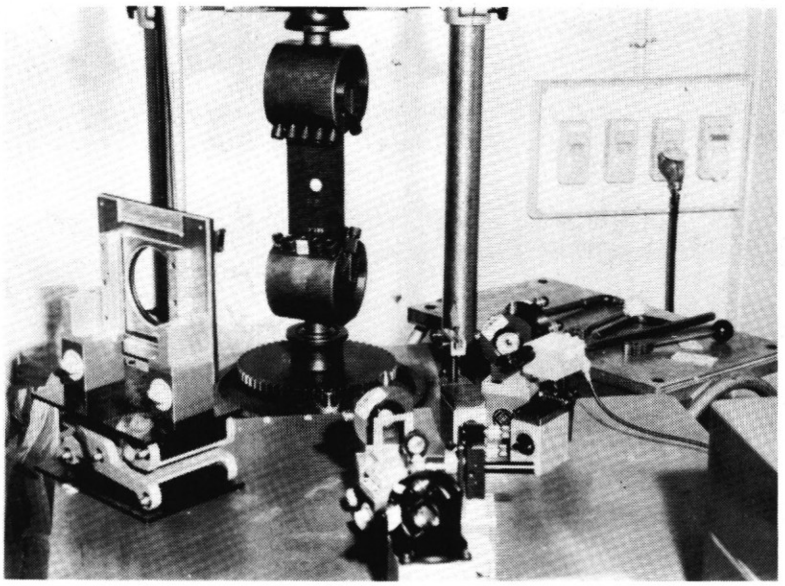


Figure 4. View of the optical arrangement in front of the fatigue testing machine

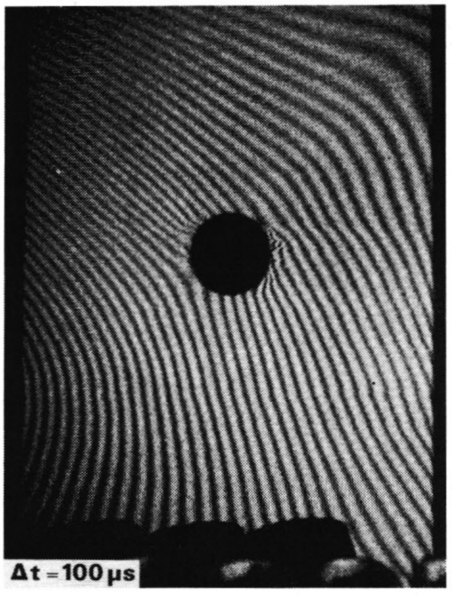


Figure 5.
Holographic view of the damage test bar showing the beginning loosening of the layers in the vicinity of the hole

Figure 6. Typical holographic view of propagation test bar with crack

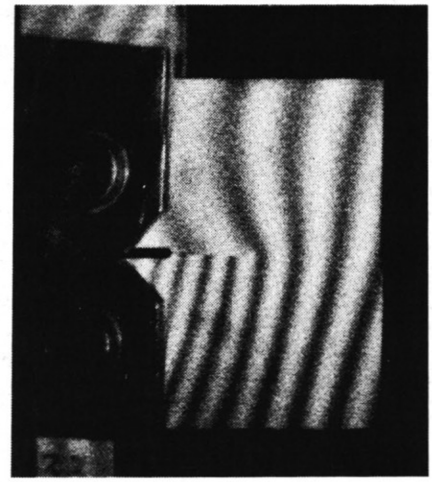
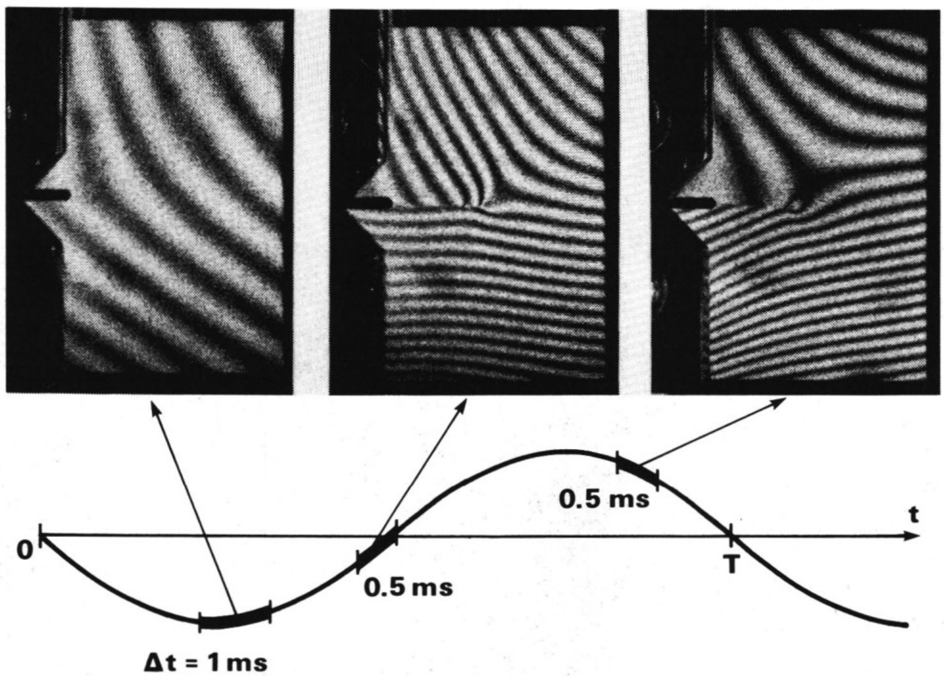


Figure 7. Propagation test bar. Visualization of the crack versus synchronization



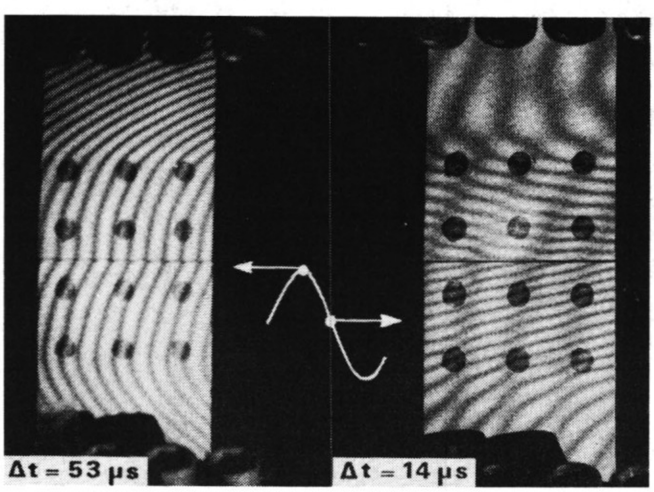


Figure 8. Holographic views of a riveted assembling during fatigue testing. Influence of the synchronization

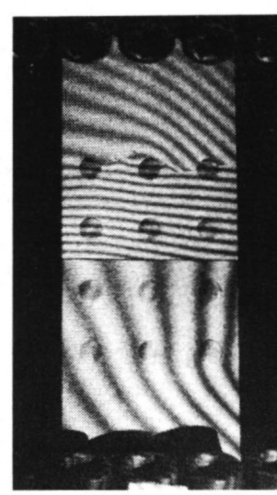


Figure 9. Riveted assembling greatly fissured.
Δt = 10 T = 102.89 ms

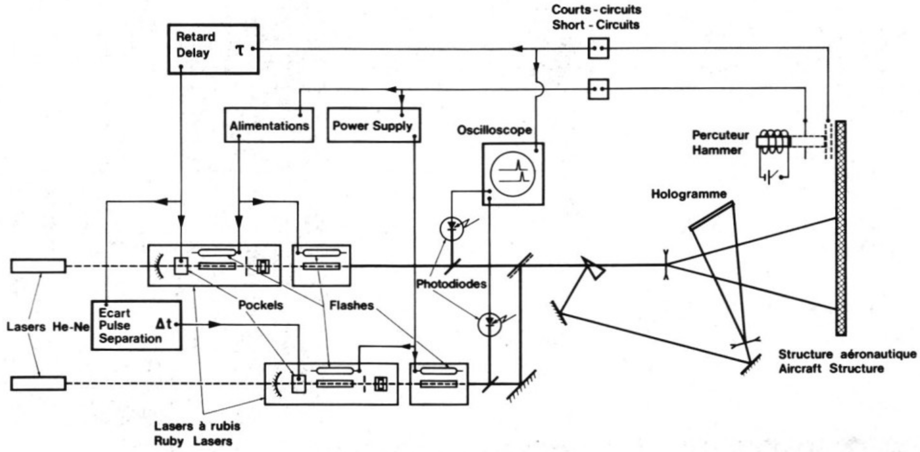


Figure 10. Schematic diagram of the holographic set-up for mechanical shock loading

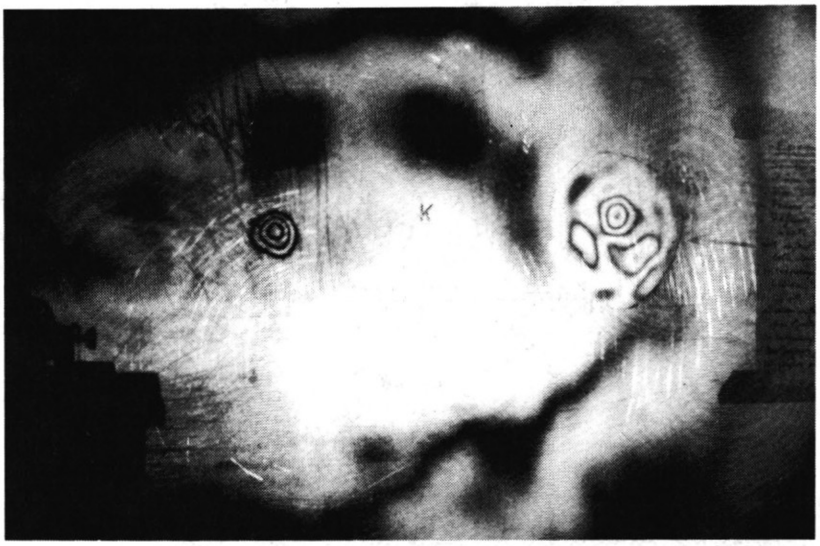


Figure 11

Double exposure holographic view of defects in aluminium honeycomb structure

τ = 2 ms

Δt = 5 μs

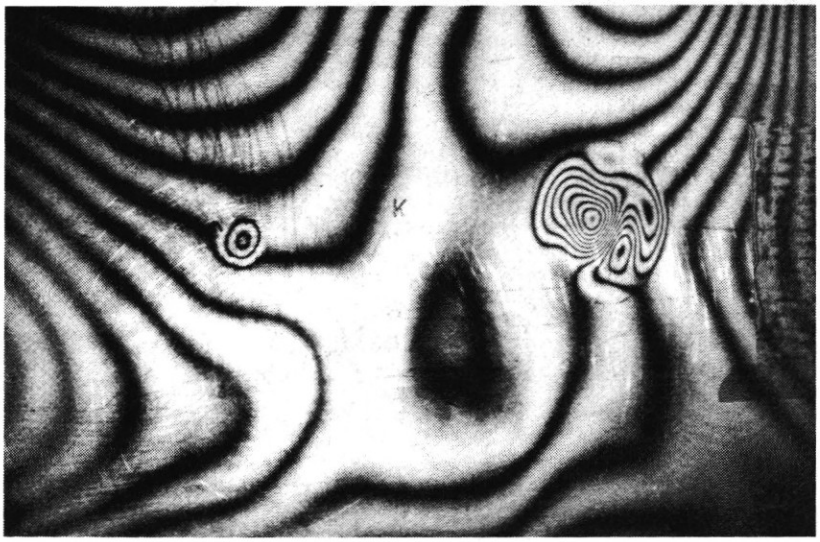


Figure 12

Double exposure holographic view of defects in aluminium honeycomb structure

τ = 3 ms

Δt = 4.7 μs

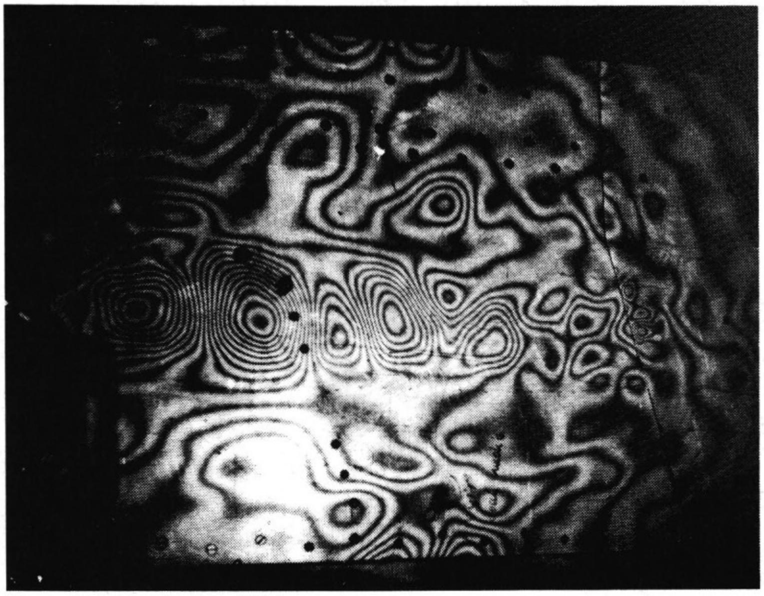


Figure 13. Holographic visualization of the field of deformations in a wing element. τ = 1 ms. Δt = 3.3 µs. With kerosene filling the interspaces

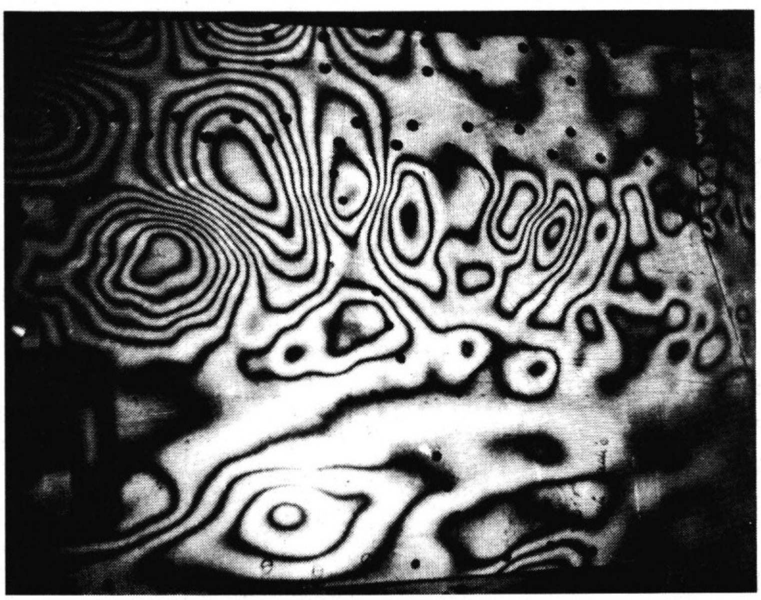


Figure 14. Holographic visualization of the field of deformations in a wing element. τ = 1 ms. Δt = 3.3 µs. Without kerosene