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Nondestructive Testing in Aircraft Construction Using Holographic Methods

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Abstract

Rapid development of high-power lasers allows the application of holographic interferometric methods in industrial aircraft construction. Holographic interferometry offers some essential advantages over other kinds of testing methods:

- Non-contact, inertialess measurement
- Object is not affected
- Two-dimensional image information
- Testing under practice-related loading
- Relevance between holographic display and damage

Today, this testing technology has arrived at such an advanced development stage that it is beyond the laboratory scale and is suited for use in the industrial manufacturing process.
Some customers already specify an imperative requirement for holographic testing of aircraft parts, such as wheels and turbine components.

The growing use of fiber-reinforeced plastics in aerospace activities entails additional applications. In composite materials holographic testing has already proved its worth.
In addition to such pure material testing, vibration processes in structures, and complete units can be investigated by holography.
The methods described will be verified by means of concrete examples.

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1. Introduction

In the field of modern optics, quite a number of new methods have been developed in the past few years finding multifarious applications in measuring technology.
The rapid development of laser and holographic technology has brought a new technique of holographic interferometry.
The different holographic-interferometric measuring methods originating from the principle of holography are applied in non-contact and nondestructive material and component testing, construction optimization, vibration analysis, high-speed physics (pulse holography). Especially for testing lightweight composite materials, such as e.g. honeycomb structures and fiber-reinforced plastics increasingly utilized in the aerospace field, which is not mastered satisfactorily by means of other physical methods, holographic interferometry is of excellent use.

Adventages include non-destructive investigations at low and freely selectable, application-related load, fast non-contact and exakt measurement by using the wavelength of light as natural scale, large extent of independence of the material and size of the objects under investigation, as well as capability for automatic evaluation of the results.

2. Techniques of Holography

The basic principle of holography is to "freeze" on emulsion the interference pattern between light scattered from an object and light in a reference beam. The pattern produced bears little or no resemblance to the object, but it stores all the information carried by the light from the object. The image of the object is recreated when the hologram - the developed plate or film - is iluminated with light identical to that used to create it (Fig. 1). A hologram can be recorded only with coherent light - that is, when the waves are perfectly in step - and for this reason the pure light from lasers is used. Reference is made to detailed descriptiens in the literature | 1, 2, 3, 4, 5, 6 |

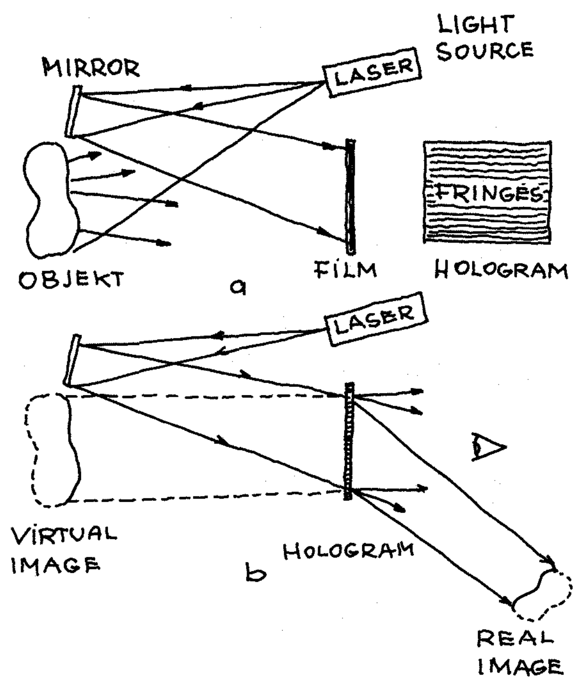

Fig. 1 Schematic diagram for recording a hologram (a) and reconstruction the wavefront (b)

In addition to the reconstruction of a three-dimensional image of an object, holography has also exhibited a promising potential for interferometric analysis by which extremely minute change in the shape of an object can be detected and evaluated.Three basic types of holographic interferometry presently exist: real-time, double-exposure, and time-average

In real-time holography, a single exposure is made with the obejct in equilibrium. After development, the holographic plate is replaced in the recording position and is illuminated with the reference beam. Any deformation of the object slightly changes the phase of the diffusely reflected object beam, and destructive interference takes place for points on the object whose phase is changed by an odd multiple of 180 degrees, i.e., an optical path length change equal to one-half of the wavelength of laser light. This destructive interference is evidenced by dark bands or fringes that appear across the virtual image. The spatial frequency and the position of these fringes can be analyzed to determine the magnitude and the direction of the deformation.

In the double exposure method, an exposure is made with the object in equilibrium as in the real-time method, but the object is then stressed and a second exposure is made before the plate is removed. The hologram is then developed an illiminated by the reference beam. Two virtual images are formed because two exposures have been made. Deformation of the object between exposures cause the phase of the object beam striking the plate to change. Dark inteference fringes will appear in the reconstruction at points on the object that have been deformed by an odd multiple of one-half wavelength.

Time-average holography is most useful in the analysis of periodic deformations of an object caused by vibration. With this technique, two position of the object are recorded because a periodically vibrating obejct is located at or near the two peaks of vibration most of the time. Upon reconstruction, interference between the wavefronts from the two virtual imaes yields information on the shape and amplitude of the vibrating areas.

3. Principle of holographic material testing

Holographic interfermetry allows the direct measurement of static or dynamic deformation of the surface of arbitrary objects. As compared to other methods, holographic interferometry offers the following advantages:

- It is an optical, non-contact measuring method. The object ist not affected by the measurement.
- The deformation ist indicated by interference fringes on the image of the object. The advantage over point methods lies in the areal image information which allows immediate identification e.g. of maximum stressed or defective areas.
- Deformation and/or amplitude distribution on vibrating objects can be determined to an accuracy of 0.1 m.

Reference is made to detailed descriptions in the literature /6,7,8,9,10/.

The deformation is indicated by interference fringes on the image of the component. These interference fringes can be considered as lines of constant deformation and/or of constant amplitude vertical to the image plane. (Comparable to contour lines on a map). Between adjacent orders of these inteference fringes the deformation and/or amplitude changes by half a wavelength of the laser light.

The priciple of holographic, non-destructive materials testing is based on the fact that defects inside a component cause a typical surface deformation which can be recognized as faultspezific deformation. A weak, defective area generally deforms in a different way than faultless zones. Even if these faulttypical deformations are only in the micrometer range, they can be clearly identified on account of the measuring accuracy of holographic interferometry.

Another advantage of holographic materials testing is that a component can be subjected to realistic stress during the test. So for holographic testing a high-pressure tube is pressurized with internal presse or a dynamically stressed part is subjected to sinusoidal or stochastic excitation. This realistic stress assures a certain relevance between holographic display and actual damage.

4. Test set-up and performance

A typical holographic set-up is shown in Figure 1.

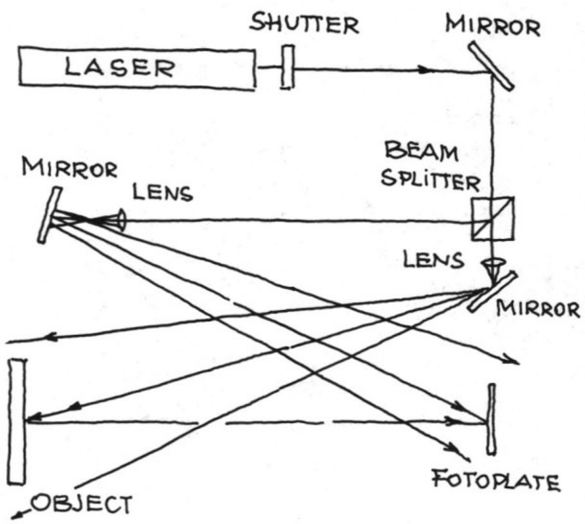

Fig. 2: Holographic set-up (schematic beam path)

The stability requirement necessitates that during the exposure time of the photosensitive layer no component moves by more than 1/10 of the wavelength of the used laser ligth.

For the investigations use was made of an argon ion laser with a holographically useable output power of 800 mW and a wavelength of 0.514 m. The exposure times are in the range of 1/30 to 1/2 sec. Hence with the continuous-wave laser only static or quasi-static problems (thermal deformation and sinusoidal vibration excitation can be investigated).

For vibration analysis of nonsinussoidal oszillations of test objects, for investigations of high-velocity flows, and for fuel injection processes a double-pulse-laser is needed.

5. Examples of application

5.1 Investigation of fibre reinforced plastic tubes

In figures 3 the holographic investigation of fibre reinforced plastic tube is shown. The toolmachine operated in bad condition. The glass fibres, which were winded helically, got a flaw at each winding period.

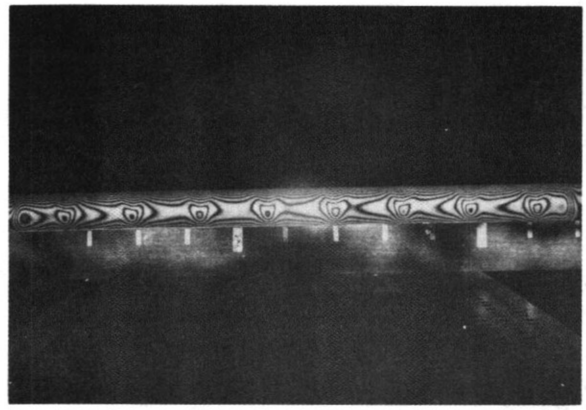

Fig. 3: Holographic investigation of fibre reinforced plastic tube; Flows at each winding period.

5.2 Holographic investigation of a cemented funktion between titanium and GFK on a helicopter rotor blad

The investigation of a cemented junction between a titanium plate and a substrate is represented in figure 4. A titanium plate is stuck on to the forward edge of helicopter rotorblades made of fiberglass reinforced plastics, to guard against erosion. A faultless adhesion is absolutely necessary in this component. Hitherto the test used an ultrasonic technique which was carried out from one point to another. With holographic methods the test costs can be reduced to about one quarter of those to date. Additionally, greater safety is guaranteed as the whole of the adhering surface is investigated at once instead of only one point at a time. Figure 4 shows a section of a prepared helicopter rotor. An adhesion fault is shown clearly by the ring shaped lines.

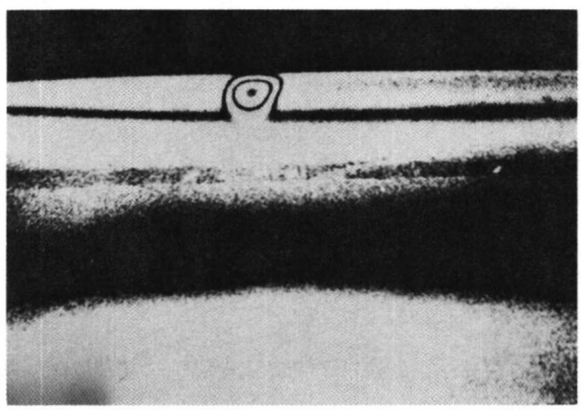

Fig. 4 Investigation of a cemented function between titanium and GFK on a helicopter rotor blade

5.3 Holographic tyre testing

Today tyres, especially aeroplane tyres are tested in series In figure 5 a part of the running surface of a radial tyre is investigated. The tyre is deformed by changing the inner pressure. Thereby the whole running surface is deformed, which is shown by the approcimately horizontal lines (basic pattern). The ring shaped lines show a deformation which is caused by a (built in) separation of a tread layer.The horizontal lines and the profile structure of the tyre make the recognition of the fault difficult.

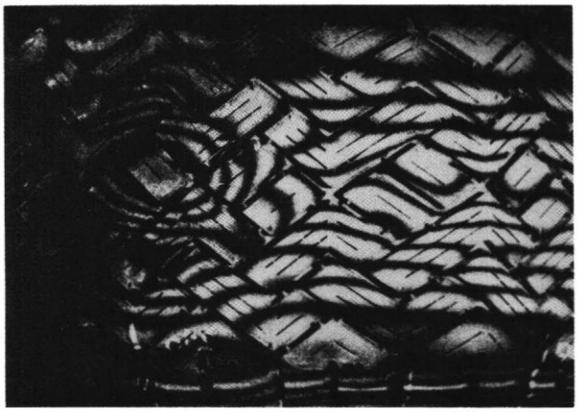

Fig. 5 Deformation picture of the running surface of a tyre. Ring shaped lines uncover a fault.

5.4 Strain measurement using white light holograms

The technique for constructing white light holograms utilizes the Bragg diffraction effect in combination with the properties of a thick photographic emulsion from opposite directions. This technique is applicable to double-exposure and time-average holographic interferometry. The experimental arrangement is shown in Fig. 6 and an example in Fig. 7.

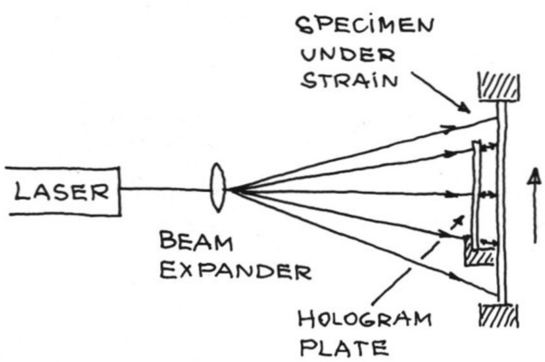

Fig. 6 Experimental arrangement for providing object motion compensation with a reflection hologram. process

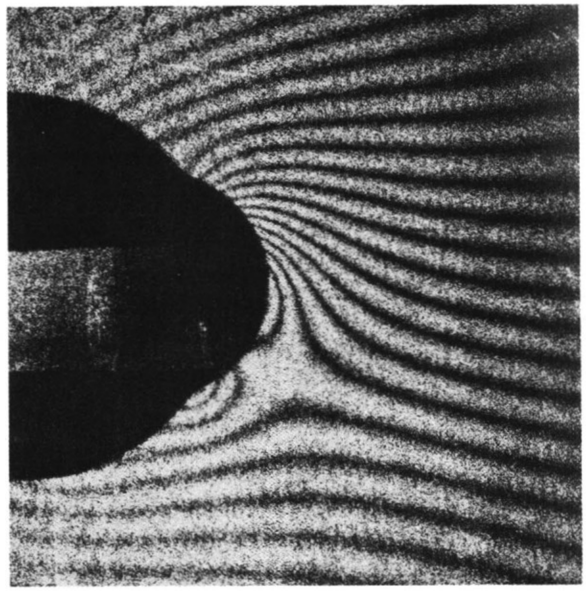

Fig. 7 Reconstruction of a double-exposure hologram with white light.

5.5. Holographic Testing of Turbine Rotors

The demonstration of turbine rotary concludes the holographic non-destructive testing. A ringformed solder seam runs on the shown turbinwheel in Fig. 8. A helicopter crashed in which people were killed due to the breaking of this solder seam.

Since then these rotaries are being holographically tested. The turbinewheels are fixed on a chuck and bent in the centre for testing. Inhomogeinities in the ringformed pattern indicates faults in the solder seam.

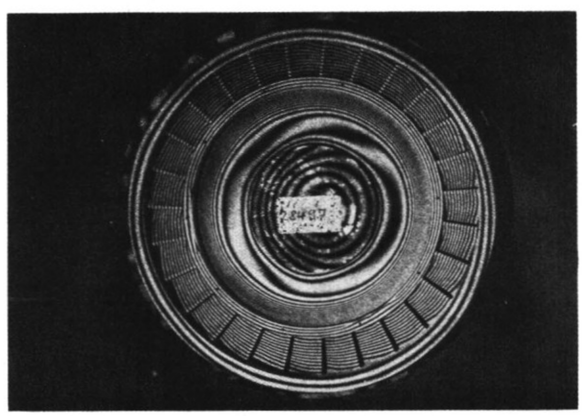

Fig. 8 Holographic Testing of Turbine Rotors. Flaws can be identified by Inhomogeinities in the form of the frings.

5.6 The measurement of thermal Deformation of an antenna (made of CFRP).

The thermal Deformation of an antenna was measured under space simulation conditions. The maximum deformation during cool-down of approx 100° K was 150 μm ± 15%.

Fig. 9 show the hologram of the antenna and

Fig. 10 the quantitative Evaluation of Deformation

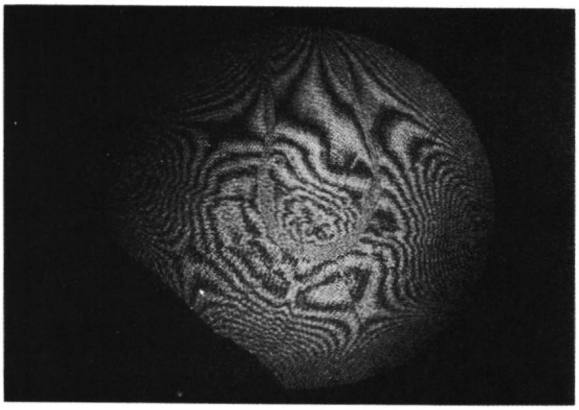

Fig. 9 Thermal deformation of an antenna (CFRP) under space simulation conditions

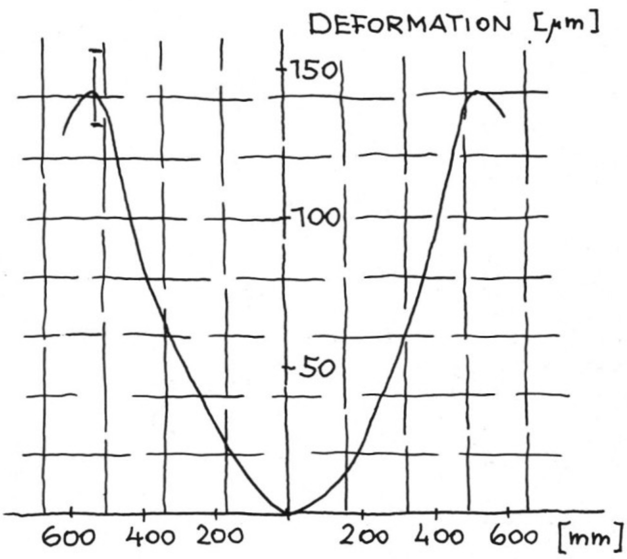

Fig. 10 Thermal Deformation of the Antenna during Cool-down from -35.6° C to -119°C

6. Other Applications

6.1 Holographic Interferometry in Transmitted light

Some other applications in which holography may be useful are the measurement of flow fields over moving projectiles and aerodynamic models in wind tunnel, the measurement of particle sizes in reacting sprays and combustion fuels.

The holographic interferometer for recording of transparent objects using a diffusing screen is shown in Fig. 11.

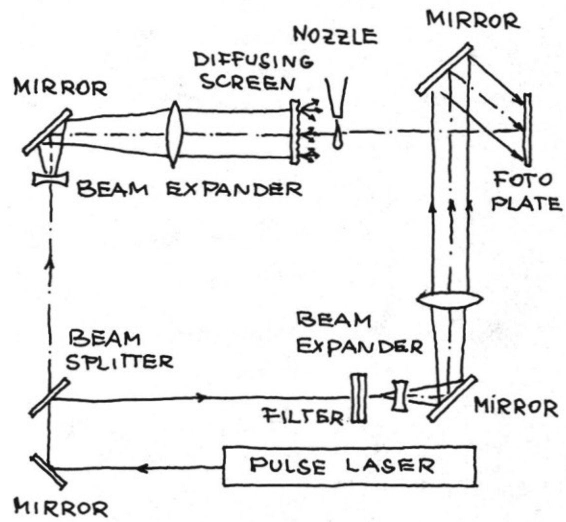

Fig. 11 Holographic interferometer for recording of transparent objects using a diffusing screen.

6.2 Measurement of the flow Field in the Vicinity of a Diesel Nozzle Jet

As yet, only qualitative information is available on the interaction of whole nozzle jet with the ambient atmosphere. We know that the air around the jet is disturbed, which gives rise to local wake or stagnation. Questions sking how great is the mass of air disturbed upon penetration of the jet into the air and the air velocity in the vicinity of the jet, have so far only been answered hypothetically. In the know publications, the air mass moved along is derived from the volume of the optically visible jet contours and the mean velocity is calculated from continuity and theorem of momentum. Experimental verification of such methods is still lacking.

By means of pulsed laser interferometry it is, however, possible to make these processes visible and to measure them. Setting of additional interference fringes (fringes with finite width) was made be slanting the mirror plane of the object beam. Pulse duration of the used pulsed laser amounted to 20 nanoseconds. The reconstructions of the single pulse interferograms Fig. 12 are showing the pressure waves in atmosphere at different injection pressures.

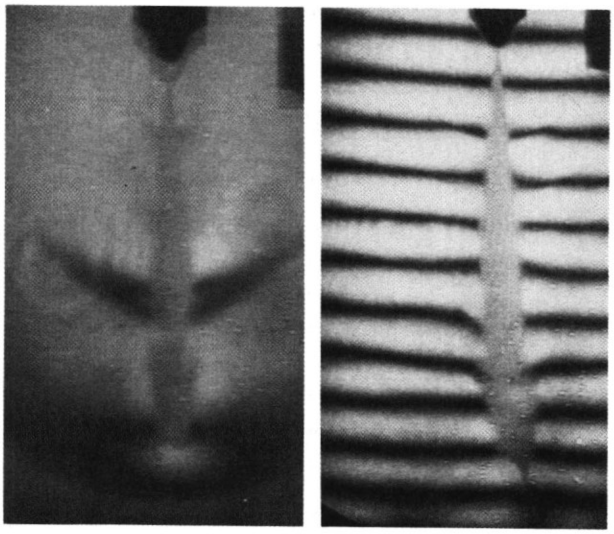

Fig. 12: Reconstructions of single pulse interferograms of a diesel nozzle jet with fringes of infinite width (left) and finite width (right).

6.3 Measurement of Jet Velocity of a Diesel Nozzle Jet

As illustrated in Fig. 13, the jet tip velocity of a diesel nozzle jet was measured by using a double pulse. The pulse duration was 20 nanoseconds and the pulse separation in each case 50 microseconds.

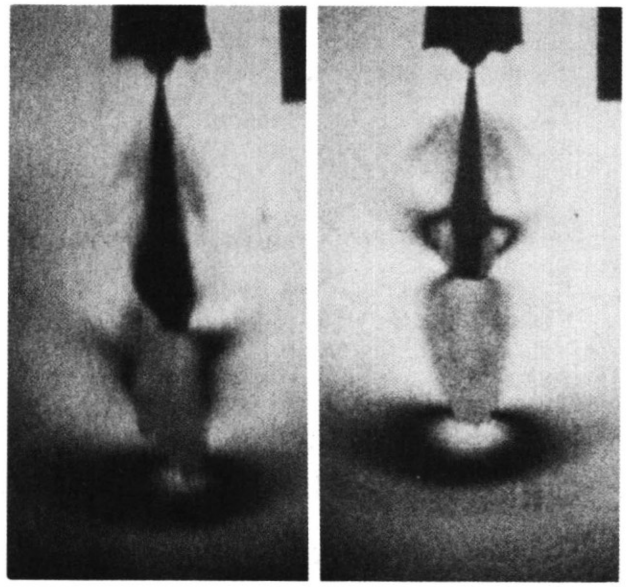

Fig. 13: Measurement of jet tip velocity using double pulse interferograms

It was for the first time possible to verify experimentally the interaction of the whole nozzle jet with the ambient atmosphere. Questions about the volume of the air mass disturbed when the jet is penetrating into the air and about the level of the air speed habe until now only lent themselves to hypothetical replies. By means of the image it can now be said that local supersonic speeds occur at individul locations in the vicinity of the injection jet.

7. Summary

This paper gives a review about the specilities of the holographic interferometry. The possibility to test different reflecting objects for the first time by the interforometry is on of the most interesting aspects of holography. Right now one can state an increasing importance of the holographic interferometry as measuring method without contact in research and technical application.

8. Acknowledgement

The anthors would like to thank Dr. Frey (IABG, Ottobrunn) for his assistance by making holograms of the CFRP antenna under simulated space conditions.

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