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To cite this version:

HAL Id: jpa-00246061
https://hal.archives-ouvertes.fr/jpa-00246061
Submitted on 1 Jan 1989

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The state of art of holographic non destructive testing in work of art diagnostics

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(Reçu le 28 juin 1988, révisé le 24 octobre 1988, accepté le 5 décembre 1988)

Abstract. — The application of holography to works of art for the diagnosis of their state of conservation or for studying the behaviour under mechanical or thermal stresses has been successfully demonstrated and described; its use in revealing damaged areas or structural alterations in embryo of both statues and panel paintings has already been proved while other possibilities are regularly coming to attention. In this paper these various applications are summarized. Some experimental results obtained in works of art diagnostics with double exposure holograms, sandwich holograms are reported.

Introduction.

Non-destructive methods have been used intensively since the '70 s in works of art conservation. The principal procedures include:

classical methods: X rays and y rays investigation; recent methods: acoustics, optical methods, nuclear techniques, XRF analysis by scattering of monoenergetic rays.

Regarding specific characteristics and applications, these techniques have the advantage of not interfering with the ancient objects under study, allowing at the same time the detection of material and manufacturing imperfections or flaws. Usually the aim of the testing is to determine the location and size of cracks, voids, discontinuities in bond surfaces, delaminations, non-homogeneous material properties, imperfect fits. In particular artifacts made of wood or marble can present several problems due to the state of deterioration of the wood or the marble. In this paper we consider the use of holographic methods for the inspection of some ancient art objects giving a particular attention to the study of modifications induced in time in materials of wood or marble by the ambient parameters variations (humidity, temperature, light).

Experimental methods.

Since 1974 double exposure and real time holography with its high sensitivity has been applied to non-destructive testing of a variety of artifacts [1-5] giving excellent results.

A very useful variation of the method, referred to as "sandwich holographic interferometry" which affords great flexibility has also been used successfully [4]. In this section we give a brief description of the basic phenomena underlying the principal techniques adopted for our inspections. Figure 1 shows the optical system used for hologram recording and reconstruction. In conventional double exposure holography, a hologram of an object is recorded, then the object is moved or deformed with
a small mechanical or thermal stress and a second exposure is made on the same holographic plate. The reconstructed image from the final composite hologram will be crossed by interference fringes strictly related to the object deformation. A detailed study of the fringe pattern allows one to yield information on the behaviour of the object as a whole during the interval of time between the exposures, while a local deviation from the overall trend of the fringe pattern is a symptom of anomalous behaviour limited to the region involved. From the minute distortions in the interference fringe pattern, we can detect the non-homogeneities or defects in the sample. Limitations of the technique include stringent requirements for mechanical stability and a restricted range of sensitivity; moreover, the two holographic images that are compared cannot be changed during reconstruction, and the choice of the time interval between exposures is casual. In recent papers we have proposed a holographic sandwich method that makes possible the composition of holographic interference images of an object from two recordings made on separate plates.

The recording sequence is normally used as follows: the object in its reference position is recorded on a back hologram through a dummy glass plate, then a series of exposures on single front plates are made at different times during the dynamic deformation. The reconstructed images from two holograms relative to different states of deformation are made to interfere; the two holograms are simply placed one in front of the other during reconstruction with their emulsions towards the object, in a plate holder which allows X Y translation of the front plate in its plane.

The image, reconstructed from the sandwich hologram with the reference beam used for recording, will give the same fringes of a conventional double exposure hologram, if the plates are paired exactly. Besides, by manipulating the sandwich hologram, unwanted fringes due to rigid body movements, that are commonly of much greater magnitude than the local deformations, can be eliminated to allow the evaluation of anomalies otherwise masked.

A series of exposures can be made at several times \(t_1, t_2, \ldots, t_k\), in a temporal sequence, in order to have a quasi-continuous monitoring of the object response to ambient parameters variations; it is possible to compare any combination of plates to study interferometrically changes in an object, that have occurred between the corresponding two exposures. Of course, for a complete treatise of the sandwich technique we refer to elsewhere [2, 5, 6].

It is clear that the above cited methods are useful for work of art non-destructive testing if a technique of stressing can be devised such that anomalies induce detectable perturbations in the deformation of the surface. Usually the stressing technique is chosen empirically with guidance provided by simple analysis of the anticipated deformation and by previous results obtained from programmed models. For our purposes, we have found, through a detailed study on models, that either a temperature gradient between the layers of the sample or a difference in thermal conductivity of the various materials are sufficient to create an appreciable local deformation in the anomaly area. All ligneous samples have been studied in thermal drift (by heating the surface with a stream of moderately warm air) and in ambient drift, under room parameters variations; for the marble objects and the stone carvings we have used microwave radiation.

**Generality on wooden artifacts.**

In this paper we refer principally to wooden artifacts (wooden panel paintings or ancient carvings). To this end, let us recall that a painting on wood can be considered as a layered structure: the wood support is coated with a number of superposed priming layers made from mixtures of gesso and glue. A frequent fault resulting from such a system is the formation of detached regions inside the layered structure. This is presumably due to the different behaviour of the wood and the priming layers with a variation of room parameters (humidity and temperature). The behaviour of the artifact as a whole, with respect to ambient parameters variations, is mainly determined by the response of the support and the state of preservation of the wood; the wood substance is anisotropic and its mechanical resistance and other aspects of its behaviour vary considerably under mechanical or thermal stresses. A force acting transversally (across the grain) can cause the wood to collapse by compression or to break by tension. Often some forces develop within the wood itself and its weakness may become extreme; even without external restraints, a piece of wood may show cracks running in the direction of the grain. In addition, destructive parasites can attack wooden specimens and cause serious damage. During their growth, the larvae make tunnels in the wood; these...
may become very extensive, reducing the interior of a panel or a statue to a kind of honeycomb without there being any external signs of damage. Wood thus riddled by parasites naturally reacts very differently from any sound wood in its vicinity and panels weakened by worms tend to crack easily. The shrinkage in the various directions due to temperature and humidity variations and worm tunnellings of the wood are the main causes of warping and other deformations in works of art. Defects in painted structures may also be due to irregular wood grain or structural anomalies. It is very interesting for art conservation to know the rate of deformation of the work of art involved under periodical daily temperature and humidity variations and how the presence of worm-tunnelling or support cracks can alter the painted surface. Preventive tests can thus allow corrective measures to be applied at an early stage.

Experimental results.
We now present some experimental results obtained by applying the above described methods to the analysis of wooden and marble artifacts.

Preliminary experiments were carried out with an unprimed wood support (30 × 40 × 2 cm) in order to obtain information on the basic components of a panel painting; the support is a panel of poplar wood (which is practically the only kind of wood support used by ancient Italian painters). Double exposure holograms were made during ambient drift with a thermal gradient $\Delta T = 1 \, ^\circ C$ between exposures, effectuated with a time interval of 1 200 s (the minimum value of temperature in laboratory environment is 13°-14°C, in the early morning; the maximum value $T = 20 \, ^\circ C$, the relative humidity doesn’t change markedly during the day, 65 %). An example of the resulting image is shown in figure 2. Some discontinuities along the trend of some of the fringes are evident, corresponding to the growth rings and to the wood grain. Other experiments were conducted on primed supports containing areas of simulated defects at several depths (Fig. 3a). The results clearly show the presence of deep detachments where (Fig. 3b) the fringes are slightly distorted, and subsurface flaws where they become locally closed [8]. Background fringes are result of overall deformation of structure. The sandwich hologram of figure 4 shows a wooden support with a

Fig. 2. — Double exposure hologram of the panel of poplar wood during ambient drift.
Fig. 3a. — Some 3-D models with simulated subsurface defects.

Fig. 3b. — Fringe patterns revealing the presence of superficial and deep detachments.
natural vertical crack, about 200 mm long, 0.45 mm wide, extending from the top to the center, treated with priming layers; the effect on the treated surface is detectable by a number of discontinuities in the fringe pattern that lie along the line corresponding to the crack.

The photographs 5 and 6 show examples of holographic tests carried out on a wooden golden carving « Angelo » of the 13th century. Some subsurface detachments at the initial stage are evident on a side of the face from a local anomaly of the fringe pattern, while on the other side the straight line character of the fringes denotes only a contraction across the grain of the wood. The photograph of figure 7 shows a sandwich hologram of the head of « S. G. Battista » (16th century); the fringe pattern has been manipulated after reconstruction so that unwanted fringes are eliminated on the face in such way the fringes at the nose reveal the presence of an ancient restoration process. The reconstruction of figure 8 shows a sandwich hologram of a wooden crucifix (painted 14th century gesso wood statue-
Fig. 5.

Fig. 6.
Figs. 5, 6, 7, 8. — Holographic tests carried out on painted wooden carvings in thermal drift.
Fig. 9. — Fringe pattern revealing the presence of a vertical crack support at the initial stage on an ancient icon.

Fig. 10. — Fringe pattern revealing the presence of a crack support on an ancient wooden panel painting of 12th century.
cases has been obtained by warming the objects with microwaves \((P = 500 \text{ w/cm}^2)\) for 15 min at a distance of one meter. The illumination source was an argon ion CW laser; emitted power was 400 mW at 514.5 nm. The holograms were recorded on 10E56 AGFA plates.

Conclusions.

Our investigations demonstrated test procedures which may be incorporated into HNDT of ancient artifacts for its characterization and for monitoring its response to stress conditions and its deteriorament due to living organisms.

In conclusion great potentialities of holographic techniques consist in:
- possibility of transferring and adapting industrial equipment and methods to the field of work of art conservation;
- possibility of controlling in real time the response of the work of art under ambient stress.

However, some limitations must be mentioned:
- complex and heterogeneous structures of works of art;
- lack of data obtained by standardized and well specified structures;
- lack of basic research on standardized sample, correlated with structures of ancient artifacts.

Further developments of this research depend mainly on providing fundamental, theoretical and experimental research on standardized and well known samples, and on comparing and controlling these new techniques with other traditional procedures.
Figs. 12, 13. — Fringe patterns from a sandwich hologram on a marble ancient Etruscan object.
References


