Laser Systems for Photobiology and Photomedicine

LASER HOLOGRAPHY AS A TECHNIQUE
IN EXPERIMENTAL MEDICINE

H. Podbielska*
Department of Electronics
The Weizmann Institute of Science
Rehovot, Israel

I. PRINCIPLES OF HOLOGRAPHY

Holography is a technique for recording and reconstructing light waves. Although a hologram is recorded on a flat surface, it produces a three-dimensional image. A conventional photograph records the real, two-dimensional image formed by a lens or a more complicated optical system. Optical detectors, like photographic film, respond only to irradiance, so only the distribution of real amplitude can be recorded and information about phase is lost. A hologram, however, records the intensity distribution that results from interference of the light scattered by an object and an additional wave coming directly from the coherent light source. When a holographic plate is developed and illuminated properly, it produces a three-dimensional image of the recorded object, thus information about both the amplitude and the phase of the scattered light is reconstructed.

The light beam from a laser source is expanded by means of a beam expander and then is divided by a beam-splitter into two beams. One of them, called the reference beam, directly illuminates the holographic film. The other beam is scattered from the surface of the object. A portion of the scattered light interferes with the reference beam at the film plane. Then the hologram is developed and placed in its previous position. When it is illuminated by the reference wave, called in this step the reconstruction wave, it produces an image which is located in space exactly where the object was during the recording step.

II. HOLOGRAPHIC INTERFEROMETRY

Holographic interferometry allows a non-contact, high resolution full-field deformation measurement of the object under examination. The technique is used extensively in industrial applications\(^1\)\(^5\) and can be used for biomedical research as well\(^6\)\(^10\). It is not restricted to investigations on models, as when using photoelastic techniques, or to pointwise analysis, as when using extensometers or strain gauges.

(*) On leave from Institute of Physics, Technical University of Wroclaw and Medical Academy of Wroclaw, Poland; recipient of the Edmond I. and Lilian S. Kaufmann Fellowship at the Weizmann Institute of Science.
Of the variety of holographic measuring methods, the most popular for biomedical applications is double-exposure holographic interferometry. In this method the object is displaced or deformed between exposures, so that two positions of the object in two consecutive states are recorded in the same recording medium. In this manner, by reconstructing the double-exposure hologram, one obtains two holographic images. Since both are coherent and exist in approximately the same place in space (if the deformation is small), they interfere with each other, producing an interference pattern. All information concerning the changes in object between exposures can be determined from this fringe pattern.

The most widely used application of double-exposure holographic interferometry is deformation analysis in experimental orthopaedics. In particular, holographic deformation analysis is of special interest in the fields of osteosynthesis and endoprosthesis research. Different types of surgical fixing devices have been studied: osteosynthesis plates of the Mittelmeier type and femur hip endoprostheses, mounted on tibial shaft AO plates under axial load or in bending and torsion. Double-exposure holographic examination of the tibia has been performed for bones loaded axially by an external fixator. The same fixator was studied in torsion and bending. The quality test of functioning of the joints connecting transfixing pins and side bars of a Hoffman-Vidal external fixator is reported by Jacquot et al. The potential use of holographic measurements can augment results obtained by contact methods.

There are several review articles describing dental applications of holography. Double-exposure holographic interferometry has been used in experimental dentistry to examine deformation of teeth, the jaw, prosthetic appliances and the skull.

A further application of double-exposure holographic interferometry relates to the study of elastomechanical properties of bones. In this way the function of the tibio-fibular complex was examined, as well as the deformations of human pelvis and human vertebrae. The human femur under bending loading was tested by this method. The rigidity of the human tibia was calculated from double-exposure holographic interferograms. This method has also been used to measure the demineralization of bones.

Using a Q-switched ruby laser, vibration and non-periodic fast processes can be studied. An example of this is an in vitro experiment on the tympanic membrane of a guinea pig. The first hologram of the membrane was made and, after some acoustic event, the second hologram was recorded on the same plate. The same technique has been applied with an intent to use it in clinical diagnostics for audiology. Human chest motion has also been investigated in vivo to assist lung diagnosis. The motion patterns originating from heart action were visualised by a double-pulse technique. Vibration analysis of the human vocal organ was carried out in vivo on the frontal part of the human neck.

Another interesting application of double-exposure holographic interferometry relates to the examination of embryonic behaviour in chicks. The prenatal motility cycles were studied in order to determine different types of movement, their onset, duration and frequency of repetition.

Another method of holographic interferometry is real-time holographic interferometry. In this method, the hologram is replaced (after processing) in exactly the same position in which it was recorded. The problem of exact positioning is solved by using in situ development or a thermoplastic camera. When looking at the object through a recorded and processed hologram, changes in the object can be seen in real-time. Biomedical applications...