PROBLEMS ENCOUNTERED IN MEASUREMENT *OF* HUMAN TYMPANIC MEMBRANE USING TIME AVERAGED HOLOGRAPHY

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Abstract

During the study of vibration of human tympanic membrane using time-averaged holography, the problems like stability of the object, coating of membrane, and measurement of intensities of laser light were encountered. This paper reports steps taken to overcome these problems in order to obtain clear and consistent holograms. Further, the factors like intensity of illumination, resolution of holographic plates, exposure time are briefly discussed in relation to the authors' work.

Introduction

In holography the brightness of the scene, film speed and shutter speed are interrelated factors. The movements of the object and the film resolution, however, limit the quality of the holograms btained. Unlike in photography, the spatial frequency components are recorded on a hologram. Several factors such as intensity of illumination, stability of the object, resolution of the holographic plates, intensities of object and reference beam and exposure time, influence the quality of a hologram.

The present authors adopted the technique of time-averaged holography in the measurement of vibration of human tympanic membrane, as this is more accurate than the methods used by Bekesy, (I960) Gilad, (1966), Brask, (1969).

By adopting this technique, the vibratory amplitude at all points on the membrane was assessed. The method is self-calibrating due to the extreme consistency of the wavelength of the laser light. However, in the application of this method, problems such as stability of the object, coating for the good reflectivity of the membrane, measurement of the relative intensity of reference beam and object beam were encountered.

This paper is a report on the methods adopted to overcome the difficulties in obtaining good quality holograms. Further, factors affecting the quality of holograms are reviewed, with reference to the present study.

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1 Experimental Specimens

Temporal bones were removed from the autopsy room of All-India Institute of Medical Sciences, New Delhi. Care was taken to choose only those cases that had expired from diseases unrelated to their ears. After gross trimming, the external canal was radically resected by means of dental drills until the tympanic membrane formed the bottom of a very shallow funnel. The picture of the exposed membrane along with the bony wall for the experiments is shown in Figure 1. These membranes were preserved in isotonic merthiolate solution, (Raghavan, *et al.*, 1974c), so that the observed properties did not depend upon the time interval elapsing between death and measurement in the laboratory.

FIG. 1

3. Problems encountered in carrying out the Study

Since the human tympanic membrane is of very small dimension (8.9 mm 8.1 mm) and thickness (0.06 mm) as explained by Raghavan *et al* (1974 d), it gave rise to some problems during the study. Twenty-five specimens were used at different stages for perfecting the holographic technique. The details are shown in Table 1.

TABLE 1. Number of specimens and the purpose for which utilized

No. of specimens	Used for
10	Fixing up the optical components on holographic table and for stability of object.
8	Fixing up the technique of coating materials.
7	Lost due to ground vibration problems.

3.1 Stability of the object

The location and the geometry of the different optical components used for the experiments is important (Raghavan *et al* 1974b). To minimize the mechanical rocking of any optical component and accidental shifts in their position, all components were mounted on heavy bases. Mechanical vibrations were minimized by placing the holographic set-up on a granite block which was placed on a wooden table. The table in turn was suspended on a combination of rubber and spring isolation mounts. This combined system considerably attenuated the mechanical vibrations reaching the holographic set-up for all frequencies above a few Hertz.

The tympanic membrane has very low stiffness (Raghavan *et al* 1974 d), compared to the metal plates on which the vibration studies by means of holography had been made previously by Powell and Stetson (1965). This low stiffness of the tympanic membrane introduced several problems and were resolved by modifying the experimental technique as detailed below.

(a) Since the tympanic membrane is very sensitive to any acoustic signal, all irrelevant noise had to be eliminated in order to record responses to the signals applied. In the absence of a sound treated room, external noise was minimised by conducting the experiments in a quiet room. In spite of this precaution, consistent holograms for the same acoustic signal were not obtained due to the ground and air vibrations in normal working hours. Thus, the experiments were conducted either late in the night or very early in the morning.

(b) Because of its low stiffness, minute air currents also displace the tympanic membrane. A good high-resolution hologram requires that the average position of the vibrating object be stationary within fractions of a wavelength of light during the time of exposure (Powell and Stetson, 1965). Movements of the tympanic membrane due to air currents were therefore very undesirable. This was minimized by mounting the experimental membrane in a three-walled acoustic chamber whose design details are mentioned elsewhere (Raghavan *et al* 1974a).

(c) Temperature changes may cause the air-volume in the middle-ear to change, displacing the tympanic membrane. To overcome this problem, the experiments were conducted immediately after the specimens had been mounted in the acoustic chamber.

3.2 Coating the tympanic membrane

The tympanic membrane is almost transparent. In order to obtain a hologram, it should be possible to reflect laser light from it. For this purpose, the tympanic membrane had to be coated with a material that had to meet several criteria.

3.2.1 Criteria for Selection of Coating Material

(a) It should not be toxic. Toxic material may cause severe damage to the tympanic membrane, such as drying or chemical alterations of the fibers of the membrane. Each of these changes affect the vibratory characteristics of the membrane.

(b) It should not load the tympanic membrane mechanically, i.e. the total mass of the coating should be small.

(c) It should not stiffen the tympanic membrane. If the coating layer is too thick or too stiff compared to the properties of the tympanic membrane, one would be observing the properties of the coating rather than those of the specimens.

3.2.2 Reflectivity

The material should have good reflectivity. The tympanic membrane is very small. If reflectivity is poor, the total amount of light reflected from it will be very small, requiring long exposure times.

Further, poor reflectivity causes greater absorption of laser light over longer periods of exposure time. This results in the heating up of the membrane.

3.2.3 Coating materials

Tonndorf and Khanna (1968, 1972) conducted their experiments by coating the tympanic membrane with 1 microme thickness of bronze powder. They also ascertained experimentally that this would not load the tympanic membrane nor change its properties. Due to the non-availability of such a finite thickness of bronze powder, a variety of other materials and solvents were tried. The details are mentioned below.

(a) Quick drying paints: Paints were applied to the tympanic membrane with the aid of a fine brush. This gave good reflectivity, but it was found that the paint solvents were generally toxic for the tympanic membrane. Also, it was observed that the amount of paint dispensed with even the smallest brush available was too much, resulting in an uneven coat on the membrane. Thus the holograms obtained were of very poor resolution.

(b) Vacuum coating: It was thought that the uniform coating of aluminium on the tympanic membrane could be obtained by adopting this method. But this was not possible, since the membrane did not withstand the amount of high pressure needed to create the vacuum in the chamber (set-up) prior to coating.

(c) Aluminium powder: Fine aluminium powder was tried because of its excellent reflectivity. The main problem was to find a suitable way of dispensing these materials, so that a thin uniform coat could be obtained. In the beginning, experiments were conducted by suspending the particles in liquid alcohol, but it was found that the particles lumped together during the drying process and non-uniform coats were obtained. Then it was concluded that

liquids of low surface-tension were required to suspend the particles because of their small size. Ether was found most suitable for several reasons. It evaporated quickly leaving behind a very uniform coat adhering directly to the tympanic membrane. There was no binding material that might become stiff nor was it toxic to the tympanic membrane. Coating was done by using a hand sprayer, so that a thin uniform coating could be obtained on the surface.

3.3 Substitute for Exposure Meter

According to Leith and Upatnicks (1967), ratios from 10:1 to 2:1 between the intensities of the reference beam and of the object beam are satisfactory in general holography. These intensities are measured with an instrument known as 'Exposure-Meter.'.

Due to the non-availability of the above instrument, the number of fringes were recorded by trial and error method. However, it was found in the reconstruction, that the exposures were not uniform and most of them were of poor quality. This necessitated designing a set-up as a substitute for the meter. The circuit diagram of the set-up is shown in Fig. 2. The photo-conductive cell (PC) was connected in series with a micro-ammeter (A) and an energister (B). The photo-conductive cell was selected in such a way that its sensitivity matched the beam power of the laser. The light beam falling on the photo-conductive cell was converted into corresponding electrical energy and this was recorded on the micro-ammeter. The readings were used to adjust the relative intensities of object beam and the reference beam, but they were not used in the calculations of vibratory amplitude.

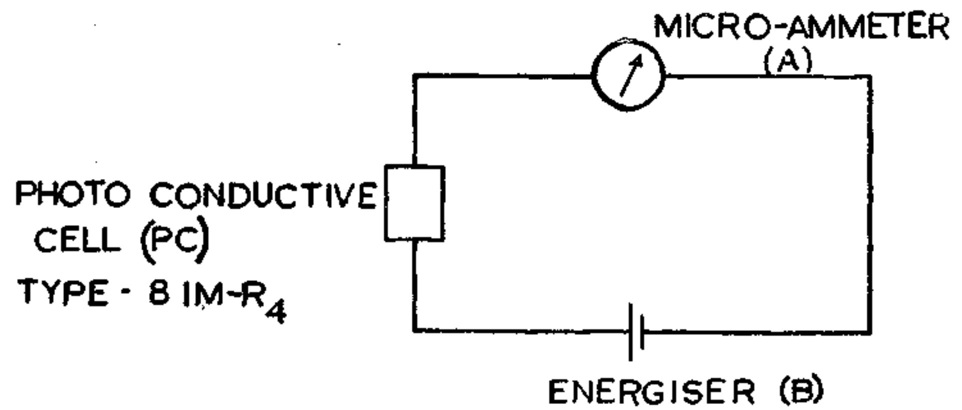

FIG.2. CIRCUIT DIAGRAM OF THE SET-UP.

The object beam intensity was measured with the above set-up. The reference beam intensity was then adjusted with the aid of the continuously variable attenuator. A ratio of 2:1 gave the best time-averaged holograms. This ratio was maintained in all holographic experiments.

4. Factors Affecting the Quality of Time-Averaged Holograms

Several of the factors which influence the quality of a hologram are discussed below:

(a) Intensity of illumination: Raghavan *et al.* (1974) found that higher order power laser decreases the exposure time and relaxes the stability requirements. However, it is to be noted that higher intensities increase the temperature of the object under study. In an earlier experiment (of authors), a laser of power 1.5 milliwatts was used. This was found to be too low a power, requiring exposure periods of 90 seconds. Also, it was found that the intensity was insufficient for clear observation during reconstruction. A 3 milliwatt power laser was employed in all subsequent experiments. The use of this laser reduced exposure periods to 40 seconds.

(b) Stability of the object: According to Brown (1969), for general holography, movements of the object should be less than $\lambda/5$ ($\lambda =$ wavelength of laser light) or approximately 10^{-5} cm during the time of exposure. For time-averaged holography, the tolerance may be even smaller. Details of the steps taken to achieve this order of stability are mentioned in 3.1.

(c) Resolution of the holographic plates: According to Leith and Upatnicks (1967), the plate resolution requirements for holography are set by both the field and the object dimensions. Diffusely scattering objects contain spatial frequencies in the order of 1,000 lines/mm. Since the dimension of tympanic membrane is much smaller than holographic plate, the plates of minimum order resolution have to be used. In the present study, Ilford He-Ne/1 plates of resolution 2,000 lines/mm were used. These gave holograms of good sensitivity.

(d) Exposure time: Optimum exposure time was determined experimentally, by varying the exposure time and judging the quality of the resultant holograms. It was found that an exposure time of 40 seconds was ideal. This period of time was maintained in subsequent experiments.

5. Conclusions

The quality of hologram is dependent upon a number of factors, such as, intensity of illumination, resolution of holographic plates, exposure time, stability of the object. These factors are independent of each other. Each factor needs to be given appropriate attention for obtaining holograms of good quality. Considerations which led to the selection of laser power output, holographic plate and the exposure time have been explained. Further, problems such as the stability of the object and the coating of the membrane were resolved. This resulted in substantial improvement in holographic reconstructions.

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REFERENCES

1. Bekesy, G. von (1960): Experiments in Hearing. McGraw Hill Book Co., New York.
2. Brask, T. (1969): Optical methods for detecting ear-drum movements. *Acta. Otolaryng.,* 68, 185-188.
3. Brown, G. M., *et al* (1969): Theory of holographic interferometry. *J. Acoust. Soc. Ammer.* 45, 1166-1179.
4. Gilad, L. (1966): Detection of ear-drum movements by Mossbauer effect. *J. Acoust. Soc. Am.,* 35, 792-805.
5. Leith, E. N. and Upatnicks, J. (1967): Recent advances in Holography: In *'Progress in optics'* ed. E. Wolf Worth Holland Publishing Co. Amsterdam.
6. Powell, R. L. and Stetson, K. A. (1965): Interferometric vibration analysis by wavefront reconstruction. *J. Opt. Soc. Am.,* 55, 1593-1598.
7. Raghavan, M. V., Abrol, B. M., and Pujara, K. K. (1974a). Study of vibration of human tympanic membrane, using time-averaged holography, presented at 19th Congress of Indian Society of Theoretical and Applied Mechanics held at Kharagpur, 1974.
8. Raghavan, M. V., Abrol, B. M. and Pujara, K. K. (1974b). Use of time-averaged holography in measurement of vibration of tympanic membrane. (To be published in Journal of Indian Academy of Sciences).
9. Raghavan, M. V., Abrol, B. M. and Pujara, K. K. (1974c). Qualitative assessment of acoustical properties in preserved human tympanic membranes. (Submitted for publication to Indian Journal of Medical Research).
10. Raghavan, M. V., Abrol, B. M. and Pujara, K. K. (1974d). Some Engineering properties of tympanic membrane. (To be published in Journal of Acoustical Society of India).