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BRITISH ACOUSTICAL SOCIETY'S SPRING MEETING.

5th-7th April, 1972.

University of Loughborough, Leics.

ULTRASONICS IN INDUSTRY SESSION.

VISUALISATION OF AN ULTRASONIC HOLOGRAM USING THE POHLMAN CELL

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General Introduction

The use of holographic techniques in ultrasonics offers the future possibility of the three-dimensional investigation of the interior structures or defects of materials. In addition, the degree of transmission of ultrasound through a soft body tissue is, unlike X-rays, dependent on the nature of the tissue. A reconstructed three-dimensional image of part of the body would appear with varying degrees of transparency, affording a valuable tool in medical diagnosis.

An ultrasonic hologram is the record across some spatial plane of the ultrasonic amplitude and phase variations occurring, due to the interference of a coherent reference beam with the diffracted object beam. Methods for the detection of this information must convert this pattern into an optical variable or pattern, from which a reconstructed image may be obtained by laser interrogation. The geometry of the image must also be analogous to the geometry of the original object.

Methods of acousto-optical conversion can, at present, be classified broadly as follows,

1. The ultrasonic image camera.
2. Mechanical scanning of the field by a piezo-electric transducer or transducers.
3. Array systems of transducers.
4. Surface deformation at a liquid-gas interface.
5. The Pohlman cell.

Advantages and disadvantages of the individual methods will not be discussed here, but the desirable qualities of any conversion device will be briefly discussed, together with some of the formidable problems to be overcome.

Firstly, the fundamental limitation on resolution is dictated by the wavelength of the ensonifying field and by the aperture of the converter relative to the wavelength. Since resolution must be obtained in depth, acoustic energy will be incident on the hologram plane at significant angles to both detector and reference. Not only must the aperture be large to accept such angles of incidence, but the recording medium must also be capable of resolving the finest fringe spacing produced i.e. at the edge of the diffraction field.

The field of acceptance is also determined by the acoustic impedance match between the recording medium and the transmitting medium, in this case, water. Piezo-electric crystals, though highly sensitive to normally incident energy, rapidly diminish in sensitivity with increasing angle of incidence. The incident beam is almost wholly reflected above about 20° to the normal, seriously limiting the field of acceptance of present ultrasonic cameras.

Sensitivity of converter response should be such as to detect levels of acoustic energy well below those needed to cause change or damage in an object being ensonified. It may be linked with the speed of response, which must be adequate to record the relevant information before any ambient change occurs. Response should also be linear over a wide dynamic range and from the viewpoint of convenience and cost, a broadband response is desirable.

Reconstruction from the hologram will normally be made with laser light. The ratio of recording to reconstruction wavelength may be as high as 3000:1 and unless linear reduction of the hologram is made in this ratio primary image distortion results. In addition, the Seidel aberrations associated with the recording geometry and significant optical and acoustic noise may be superimposed.

Investigation of the feasibility of the Pohlman cell as a holographic imaging device is being undertaken as part of a wider contract concerned with flaw detection. The frequency of operation is from 1-12MHz. In its original form, the cell was used to directly visualise acoustic fields but it would appear that little or no work had been done to see whether, if at all, the cell was capable of responding to and recording the fine modulation of intensity and phase characteristic of a hologram.

Basically, the cell depends for its functioning on the 'Rayleigh disc' effect, whereby a rigid, disc shaped object placed in a liquid or gas, experiences a torque when exposed to a direct or alternating flow of the medium. The torque tends to turn the disc so that its plane lies at an angle to the flow determined by the velocity amplitude of the medium particles. Particle displacement and the consequent alternating flow due to an ultrasonic field also produces a torque dependent on the ultrasonic intensity at the point. Fine aluminium flakes, acting as 'Rayleigh discs' are suspended in a light organic liquid and align locally in the field, specularly reflecting light shone on the rear optical face. A brightness modulation results, dependent on the ultrasonic intensity at the point.

The front face of the cell is a thin, tensioned membrane acoustically transparent at the frequency being used and the overall thickness of the active medium of the cell is about 1 mm.

Experimentation from 1-3MHz indicates that extension of the frequency range up to 10MHz is feasible. Resolution capacity of the recording medium is dictated by the average dimension 'd' of the flakes, and if $d \ll \lambda$, the resolution will be high. A real reference beam must be used and the response time necessitates C.W. operation. Reverberation must be minimised, the cell being quite sensitive to extraneous reflections.

Relatively large apertures are possible and cell designs of 10 cms and 25 cms diameter have been employed in the initial work, the first of these having a movable acoustic face, whereby the cell thickness may be tuned for optimum sensitivity.

Summary of results

Results so far obtained with the cell are encouraging and indicate a high resolution in the detail recordable. Registrable quality appears to be limited by deficiencies in the acoustic sources and the illumination system. Approximate estimations of sensitivity, made by previous workers, have been verified at about 1 watt/metre ^{2}, and at this intensity the response time of the cell lies between 0.5 - 1 sec. Dynamic range appears to be nearly 30dB, as predicted theoretically.

Precipitation of the aluminium flakes is not a serious problem, but flake size must be reduced, as the frequency is raised, being approximately 20μ cross-dimension for maximum sensitivity at 1MHz. The rate of precipitation decreases with decreasing flake size and detail registered does not deteriorate for several minutes.

High contrast and clarity are obtainable in both diffraction fields and fringe patterns characteristic of a hologram. Maximum fringe spatial frequency registered at 3MHz was 30cm^{-1}, limited by cell geometry and with reference and object beams at 45° to the normal. Larger angles of acceptance are possible, due to the excellent match of the acoustic face and recording medium to the water.

A series of simple holograms of metal objects have been photographed and analysis of several of these, recorded at 2 and 3MHz, have produced reconstructed images of the original object, but with varying degrees of both noise background and 'speckle' in the images.

In conclusion, the cell appears to offer a very convenient and rapid method of visualising diffraction and interference phenomena associated with ultrasonic fields. Refinements of technique are required, but the excellent resolution suggests that recording at frequencies up to 10MHz is feasible. Recording of hologram detail has been demonstrated and although higher frequencies will improve resolution in the reconstructed image, attention must be paid to reducing background noise and 'speckle', associated with the high coherence. Holographic imaging of the interior of objects at least partially transparent to ultrasound should be possible with this device.

Acknowledgements

This work has been supported by the Ministry of Technology, latterly known as the Procurement Executive, Ministry of Defence, to whom the author is greatly indebted. His thanks are also due to Professor J.W.R. Griffiths for supervising the project and stimulating it by his constant interest.