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ULTRASONICS IN INDUSTRY SESSION.

SOME NEW DEVELOPMENTS IN ULTRASONIC VISUALISATION FOR N.D.T.

by

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INTRODUCTION

The idea of visualising ultrasound is not new, nor is the concept of forming visual images of defects in materials; methods which have been demonstrated include 'B-scan' and holographic techniques.

This paper describes work using inexpensive visualisation methods for studying the behaviour of ultrasound. Also described is a new approach to materials inspection whereby ultrasonic reflections from defects are focused in a manner somewhat analogous to an optical camera. An ultrasonic visualisation method is used in place of the film, and by employing pulsed ultrasound in conjunction with stroboscopic illumination the ultrasonic reflections from defects are made visible only at the places where they come to a focus. Since the visualisation methods used are inherently 3-dimensional the system is potentially capable of giving an instantaneous display of defects in their correct spatial relationship, and this is achieved without conversion of sonic signals to electrical ones and without the need for coherent light sources.

This system has been named Direct Ultrasonic Visualisation of Defects, abbreviated to D.U.V.D. Among the features which need to be resolved to make it practicable are; the visualisation technique, the stroboscopic light source, the generation of suitable ultrasonic pulses and the sonic focusing system. Progress in these fields will now be described.

VISUALISATION METHOD

The two visualisation methods investigated, with a view to their use in a defect visualisation system, are the photoelastic method and the schlieren method. With each, we have concentrated on the visualisation of repetitive pulsed ultrasound.

The photoelastic method is by no means a new technique for viewing ultrasound: during the last twenty years, various writers have described its use in this context. Nevertheless, it seems to have become, in recent years, a somewhat neglected method, which is perhaps surprising in view of certain advantages it has over its most immediate rival, the schlieren technique. Both methods depend upon changes in the refractive index of a material due to the action of stress - in our case, stress produced by an ultrasonic wave - but the photoelastic method can render visible only those regions in a solid in which stress differences (and hence induced refractive index differences) exist along mutually perpendicular directions. Thus, by its nature, photoelasticity can be used for visualising in solids only (transparent, of course); but since in non-destructive-testing applications ultrasound is most commonly used in testing solids, visualisation in solid materials, with both shear and longitudinal waves present, will often be of greater relevance than visualisation in liquids. The authors have found the method to be more sensitive for solids than its schlieren counterpart, though to generalise here would be unfair, since a direct comparison with highly sophisticated schlieren equipment, such as that at Tube Investment Research Laboratories, has not been made.

A simple visualisation set-up using photoelasticity will be described at the Conference, and examples of the visualisation of pulsed ultrasound will be shown. The following will be discussed also: choice of visualising material; sensitivity; possible applications of the technique; and its advantages over the schlieren method.

The photoelastic method was found to be insufficiently sensitive for adoption in a practical D.U.V.D. system, which demands a technique of the highest possible sensitivity in order that defects of a realistic size can be detected. The schlieren technique responds to refractive index gradients, and hence to the stress gradients produced by an ultrasonic wave in either liquid or solid. If we define sensitivity in terms of the ultrasonic power required for adequate visualisation, the best sensitivity is obtainable using a schlieren technique combined with a liquid visualising medium; such a system has therefore been investigated, bearing in mind the obvious need for compactness of design. A brief description of schlieren equipment built on a one metre optical bench will be given, and the sensitivity obtained will be discussed.

STROBOSCOPIC LIGHT FLASH

Defect images displayed using D.U.V.D. will be "smeared" to an extent increasing with the duration of the stroboscopic light flashes used and their time jitter relative to ultrasonic pulse emission. An unnecessarily long light flash duration (and/or time jitter) will also reduce the sensitivity of the visualisation technique, be it of either type. A further factor controlled by the light flash properties is the degree to which the fine structure of ultrasonic pulses can be resolved; this could be particularly important in practical applications of photoelasticity, since, given a suitable light source, the exact form of an ultrasonic wave could be displayed, showing individual compressions and rarefactions (and perhaps facilitating the measurement, by means of a compensator, of the stress distribution within a pulse). For best sensitivity and minimum smearing in D.U.V.D., and for "wave-form" display with photoelasticity, it is assumed that light flashes of duration about one quarter of the period of the ultrasound being studied, with time jitter considerably less, would be required. For 5MHz ultrasound - of particular interest to us - a flash duration of about 50 nanoseconds is indicated.

The light source used for most of the work to date was a General Radio "Strobotac", Type 1538-A, the most suitable commercially available stroboscope. The duration of the flash given by the "Strobotac", which uses a xenon-filled discharge tube, has been measured as about 250 nanoseconds (between half-peak intensity points), and its time jitter as typically 150 nanoseconds. To replace the "Strobotac", a spark light source, believed to be of original design, has been developed; this gives flashes of duration about 40 nanoseconds with time jitter very much less. The new source, which is compact enough to be mounted unobtrusively on a small optical bench, uses two "active" electrodes only, rather than the more conventional three-electrode spark source which has two main electrodes plus a trigger electrode situated in the main gap.

Early experiments have confirmed that ultrasonic pulses from a 5MHz transducer can be "resolved" using the new source, and it is hoped to show photographic examples.

ULTRASONIC PULSE SHAPE

Undesirable image "smearing" in defect imaging systems increases with ultrasonic pulse duration as well as with light flash duration. What is required, then, having decided upon the maximum allowable ultrasonic frequency, is a highly-damped ultrasonic pulse from a transducer of that frequency (5MHz in our case). Now, in the proposed D.U.V.D. system, the ultrasonic transducer is bonded on both sides to solids (though perhaps later on one side only). Using the methods proposed by Redwood (see reference) to construct graphically the shape of the pulse emitted from such an arrangement, one finds, in theory, that short very highly-damped pulses should indeed be obtained, their exact shape depending on the shape of the applied voltage pulse.

The question then arises as to whether practical methods of bonding can be made to produce results close to theory. Using low-melting-point solders and carefully controlled techniques, ultrasonic pulse shapes close to those predicted have indeed been obtained. The true acoustic waveform of an ultrasonic pulse can be displayed on an oscilliscope using, as a detecting element, a transducer of low resonant frequency with suitable electrical shunting (again after Redwood). Examples of highly-damped pulses obtained with soldered transducers will be shown.

ULTRASONIC FOCUSING

Ultrasonic waves can be focused in a manner analogous to optical focusing, using either a lens or a curved interface between two media of different sonic velocities. Such an arrangement gives different transverse magnifications for different object distances, so that, since the visualisation method is 3-dimensional, the image field becomes a distorted version of the object field. This distortion would not be tolerable for the present purpose; the focusing system employed must have constant longitudinal and transverse magnificatioss for all objects, a property which we call 'linearity'.

Also, since the system is required to display simultaneously the images of defects at different depths in the material under inspection, it is necessary that the sonic images of all defects in a 3-dimensional field come to their respective foci at the same instant in time. This property is called 'isochronicity'.

Fortunately, linearity and isochronicity can be simultaneously incorporated in a focusing system, and the necessary constraints may be embodied into a practicable assembly of three or more media with curved interfaces at their junctions.

The analysis for finding suitable focusing configurations is best performed, in the first instance, on the assumption that paraxial conditions apply (as is done in elementary optical design). The resulting constraints are expressed as equations connecting the dimensions of the configuration, but for design purposes it is much more convenient to display the constraints in graphical form. Design charts have been evolved which allow the effects of different choices of media to be seen at a glance, and which indicate directly the radii of curvature required at the interfaces.

COMPUTER-AIDED DESIGN

The paraxial analysis permitted practical demonstrations of

D.U.V.D. (to be illustrated at the Conference) but for more detailed analysis the use of ray plotting methods is necessary. A computer program for this purpose was developed, and was applied to configurations derived from paraxial analysis. The behaviour for near-axial objects and near-axial rays proved to be as anticipated, and the expected aberrations and field distortions were exhibited for large cones of rays or large off-axis distances.

A further computer program was therefore written to generate aspherical surfaces for removing these unwanted effects; with its aid it proved possible, by adding an aspherical element to a configuration having two spherical interfaces, to achieve (as a 'paper exercise') adequate focusing performance over a 3-dimensional field of reasonable size. The aspherical element required lends itself to construction by conventional engineering methods.

DEMONSTRATIONS OF FEASIBILITY OF D.U.V.D.

For use with the photoelastic method of visualisation, a configuration having two spherical interfaces, using quartz plus steel for the first medium, mercury for the second and quartz for the third, was constructed; the steel part was provided with a milled slot to represent a defect. Successful imaging of the resulting pattern of steel surfaces was obtained, displaying correctly the scaling relationships anticipated from theory.

A further demonstration, for use with the more sensitive schlieren method of visualisation, was constructed. For this, a mercury lens was used in place of the first spherical interface, the media becoming: steel, mercury, quartz, and water. By this means the embarrassment of a large mass of mercury was avoided. Imaging was again demonstrated, using rather more realistic 'defects' than for the previous demonstration.

IMPROVED VIEW OF IMAGES

The schlieren method, which is the most attractive means of visualisation for D.U.V.D., is conventionally applied to produce an image either on a screen or on camera film. Since the ultimate objective of the present project is to construct a portable inspection device for use in industrial environments, presentation of images in this form would be inconvenient. A change is therefore made to the conventional arrangement, whereby the observer's eye is placed at the knife edge plane. By this means, the observer sees the visualised ultrasonic images directly in the medium concerned (water in this case).

An arrangement as described has the disadvantage that the eye must be placed in a precise position, and even then viewing is monocular. A modified version of the conventional method has therefore been developed in which graticules are used instead of knife edges. The result is that exact placing of the eye is not necessary, and further the 'viewing slot' may be made large enough to embrace both eyes of the observer, thus giving binocular viewing, with a stereoscopic impression of the 3-dimensional information in the image. With proper attention to the optical light control arrangements, brightness is adequate for viewing in normal daylight, despite the limited light output of the sources used.

This binocular arrangement will be demonstrated at the Conference.

REFERENCE.

REDWOOD, M., A Study of Waveforms in the Generation and Detection of Short Ultrasonic Pulses, Applied Materials Research, 2, April 1963, pps 76 - 84