ACOUSTICAL IMAGING SYSTEM
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ABSTRACT OF THE DISCLOSURE

A system for electroacoustically producing images of objects placed in an ultrasound transmitting medium which is coupled to a piezoelectric transducer. The coupling includes a sonic waveguide for accepting acoustic energy through a large angle of incidence and directing the energy to the transducer at a normal angle of incidence.

BACKGROUND OF THE INVENTION

Field of the invention
Ultrasound image producing systems.

Description of the prior art

A fundamental problem arising in prior art ultrasound image producing systems and, in fact, in any acoustical system involving the transfer of energy from one media to another is the reflection of acoustical energy at the interface between the detecting medium and the coupling medium due to the differing acoustical impedances of the media.

When the ratio of acoustical impedances of the media is high as for example when one medium is a piezoelectric detector such as a quartz plate and the other medium is a liquid such as water, then the critical angle of incidence for total reflection of acoustical energy may be quite small. Thus, the effective aperture or output of the system when used for imaging purposes is seriously restricted by a substantial loss of acoustic energy by reflection from the detector back into the coupling medium.

The present invention overcomes this restriction with coupling which greatly increases the angle through which acoustic energy will be transmitted through the coupling medium in a system of the aforesaid type.

SUMMARY OF THE INVENTION

According to principles of this invention, the acoustic energy acceptance angle at the interface of a detector medium (e.g., piezoelectric plate) and coupling medium (e.g., water) is greatly increased by the provision of a waveguide structure which will accept energy through a large angle and, in turn, propagate this energy into the detector medium at a normal angle of incidence.

The waveguide is placed immediately adjacent to the detector plate in the coupling medium and comprises a rigid matrix of acoustical waveguides each in the form of a hollow channel extending right angularly toward the detector plate. Each channel is of a diametral size in the order of a wavelength of the acoustic energy applied to the image producing system so that a single mode piston type propagation of acoustic energy will take place axially thereof and accordingly be received by the detector plate at a zero angle of incidence. Such energy propagation will be excited at the entrance aperture of each channel through a large angle of incidence of incident acoustical energy and the channel, in turn, will deliver this energy only along its axial direction.

Details of the present invention will be more fully understood by reference to the following detailed description and the accompanying drawings.

DESCRIPTION OF THE DRAWING

FIG. 1 diagrammatically illustrates an acoustical image producing system which is exemplary of a type to which the improvement of this invention is applicable;

FIG. 2 is a greatly enlarged fragmentary cross-sectional view of a portion of the system of FIG. 1; and

FIG. 3 is a greatly enlarged fragmentary cross-sectional view similar to FIG. 2 wherein details of the present inventive concept are illustrated.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 diagrammatically illustrates an electroacoustical image producing cell 10 having an electron image converter tube 12 associated therewith. This unit is exemplary of a type of system to which the present inventive concept is applicable.

Cell 10 includes tank 14 having a window at one end in the form of a piezoelectric image transducer (e.g., a quartz plate) which will be referred to hereinafter as image detector 16. At the opposite end of tank 14 is ultrasound generator 18 preferably in the form of a crystal transducer capable of producing acoustic energy of frequencies in the order of from 1 to 20 megacycles per second.

Tank 14 is filled to a level above image detector 16 with an ultrasound transmitting coupling medium 20 (e.g., water) which transmits acoustic energy from generator 18 to detector 16.

An object 22 intended to be nondestructively examined by ultrasonic imaging is immersed in the liquid coupling medium between generator 18 and detector 16. Object 22 may be an industrial product such as a weldment or the like or an in vivo or excised biological specimen.

Sound waves 24 produced by generator 18 in coupling medium 20 which become incident upon object 22 are suppressed, partially absorbed, differently refracted and/or otherwise modified according to the external configuration and/or internal structure or nature of the object during transmittance therethrough. Such sound waves, some of which are illustrated by arrows 25, may be considered as image forming waves. Their effect upon detector 16 is to induce electrical charges on surface 26 of piezoelectric detector 16 of values corresponding to the position of incidence and respective sonic pressures applied thereby upon detector 16. Thus, the ultrasound field of waves 25 is converted to what may be termed as an electrical image of object 22 located on the piezoelectric surface 26 of detector 16.

Image converter tube 12 is illustrative of means which may be employed to convert the aforesaid electrical image into a modulated electrical signal which in turn may be applied to the scanning circuit of a conventional cathode ray tube for visual display of the image.

Tube 12 having electron gun 28 scans surface 26 of detector 16 with electron beam 30 whereupon secondary emission electrons produced by the incident scanning beam are modulated by the piezoelectric voltage present on surface 26. The modulated secondary emission electrons 32 are induced by accelerating mesh 34 into electron multiplier 36 from which, through lead 38, the signal may be directed to a cathode ray display tube (not shown).

The system thus far described is conventional and its operation, though only briefly described hereinabove, would be thoroughly understood by the artisan.

Heretofore, however, the transfer function of acoustical energy to electrical energy by the piezoelectric detector 16 of such a system has been seriously restricted by reflection, back into coupling medium 20, of large amounts of acoustic energy incident upon the receiving face 40 of detector 16.
This is illustrated in FIG. 2 wherein angle \( i \) represents a critical angle of incidence at which total reflection of acoustic energy takes place and arrows 42 and 44 represent paths of image forming acoustic energy incident upon face 40 at angles larger than the critical angle. This reflected back into coupling medium 20, as shown, and acoustic energy is, accordingly, totally internally reflected back into coupling medium 20, as shown, and fails to excite detector 16.

Angle \( i \) has been chosen arbitrarily since it will become apparent that whatever this angle may be, as determined by the relative acoustical impedances of the detecting and coupling media, the present invention deals with the matter of considerably improving the energy transfer function in electroacoustic systems as follows:

In FIG. 3, piezoelectric detector 16 is provided with waveguide 46 placed against the detector 16—coupling 20 interface.

Waveguide 46 comprises a rigid matrix of hollow channels 48 which are axially right angularly extended toward face 40 of detector 16. The diametral size of each of channels 48 is in the order of a wavelength of the sonic energy produced by generator 18.

Each channel 48 is surrounded by a relatively thick wall 50 which gives the waveguide structure sufficient rigidity to be itself nonvibratile in the coupling medium 20.

Waveguide 46 may be formed of various metals such as aluminum, copper, brass or steel or of certain glasses and plastics or their equivalents. Preferred materials would be those which would provide the aforesaid rigidity of structure with minimum thicknesses of walls 50 or, in other words, with a maximum number of channels 48 per unit of surface area. The waveguide may be cemented or otherwise attached to surface 40 of detector 16. Alternatively, it may be supported immediately adjacent to surface 40 by suitable brackets or the like (not shown) extending from, the side walls and/or bottom of tank 14 (FIG. 1).

Operation of the acoustic image transducing system with waveguide 46 (FIG. 3) is as follows:

Paths 42 and 44 (FIG. 2) of image forming acoustic energy which, as already mentioned, would ordinarily be totally reflected by face 40 of detector 16 are reproduced in FIG. 3 to illustrate the entirely different energy transfer effect produced by waveguide 46.

These paths 42 and 44 of acoustic energy, upon incidence at the entrance aperture of a waveguide channel, induce a single mode piston type propagation of acoustic energy axially thereof as represented by arrows 42a and 44a and by lines 42b and 44b. This energy then being directed right angularly (i.e., flatly and well within the critical angle \( i \) of incidence) against face 40 of detector 16 in each case, now excites the detector to produce electrical charges by piezoelectric action on its surface 26 which charges are positioned and quantitatively representative of the image forming acoustic energy propagated along paths 42 and 44 at angles considerably greater than the aforesaid critical angle.

Image forming acoustic energy normally being propagated in medium 20 toward detector 16 within the critical \( i \), as represented by arrow 52 (FIG. 3), is, naturally, largely propagated through a particular one or plurality of channels 48 against whose entrance apertures this energy becomes incident. From the foregoing it can be seen that acoustic image forming energy incident upon the transducer coupling system of this invention (FIG. 3) at all angles within and greatly larger than the normal critical angle of incidence for such coupling systems is effectively utilized with the result of considerable and important improvement in the energy transfer function of the system. This, of course, carries through to a corresponding improvement in the conversion to a signal for visual display or recording of acoustic images by whatever means (e.g., tube 12) may be employed to effect such a conversion.

I claim:

1. An acoustical imaging system having an acoustic energy transmitting medium of one acoustical impedance interfacially coupled to a transducer medium of a different acoustical impedance and means for generating acoustic energy in said transmitting medium wherein the improvement comprises:

an acoustical waveguide positioned at said coupling interface, said waveguide having a number of juxtapositioned energy transmitting channels in a matrix material with each channel having an entrance aperture exposed to said energy transmitting medium for receiving acoustic energy generated in said transmitting medium.

2. An acoustical imaging system according to claim 1 wherein said transducer is a piezoelectric plate having an acoustic energy receiving face immediately adjacent to which said waveguide is positioned with said channels extending perpendicularly from said face into said energy transmitting medium.

3. An acoustical imaging system according to claim 2 wherein the matrix of said waveguide is nonvibratile when subjected to said acoustic energy.

4. An acoustical imaging system according to claim 2 wherein said energy transmitting medium is a liquid and an object to be imaged is immersed in said liquid between said acoustic energy generating means and waveguide whereby said generated energy is modified by transmittance through and around said object and is received by said waveguide as image forming acoustic energy.

5. An acoustical imaging system according to claim 4 wherein said image forming acoustic energy is received by said waveguide through angles less and greater than the critical angle of incidence for said coupling interface as determined by said acoustical impedances of said transmitting and transducing media and is transmitted through said waveguide channels to said face of said plate at normal angles of incidence for piezoelectric conversion by said plate into electrical image forming energy.

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