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[45] **Sept. 2, 1975**

[54] **ULTRASOUND IMAGING SYSTEM UTILIZING SHAPED ACOUSTIC MATCHING ELEMENTS TO INCREASE THE EFFECTIVE APERTURE OF AN ACOUSTIC TRANSDUCER**

[75] Inventors: **John E. Jacobs**, Evanston; **Donald A. Peterson**, Lincolnwood, both of Ill.

[73] Assignee: **The United States of America as represented by the Secretary of the Department of Health, Education and Welfare**, Washington, D.C.

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[52] **U.S. Cl.** ..... **340/5 MP**; 73/67.5 R; 310/8.3; 340/8 MM

[51] **Int. Cl.** **H01j 31/495**; H01r 17/00

[58] **Field of Search** ..... 340/5 MP, 8 MM, 10; 310/8.1, 8.2, 8.3; 73/67.5 R, 67.5 H

[56] **References Cited**

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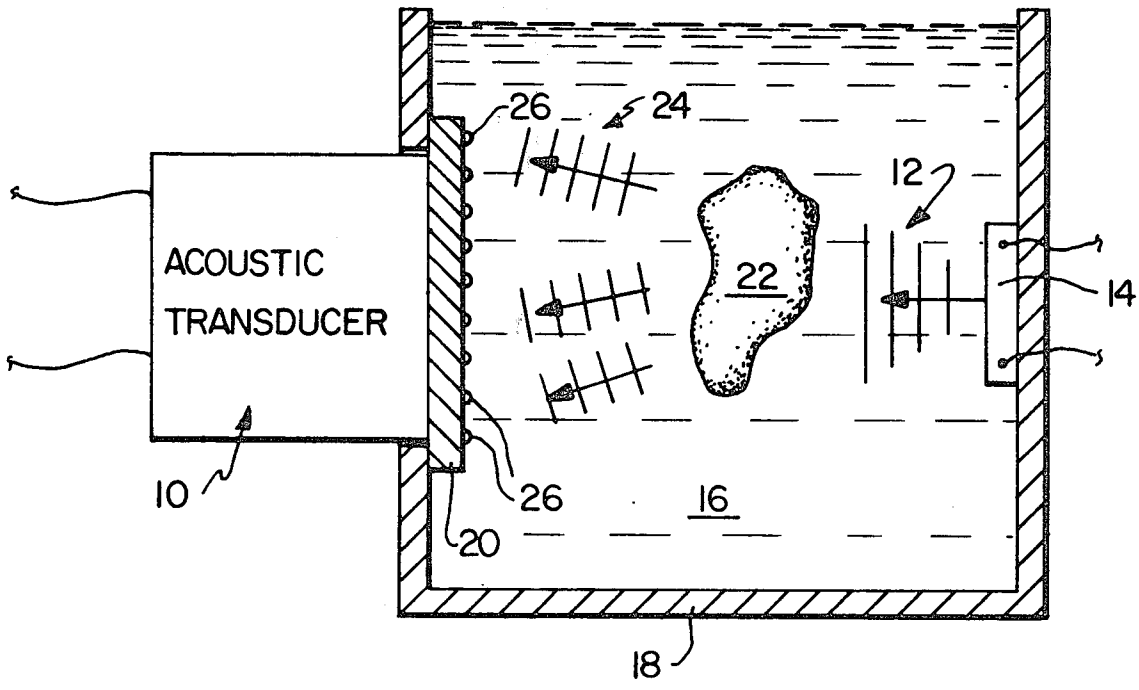
3,541,848 11/1970 Thurstone ..... 340/5 MP

Primary Examiner—Richard A. Farley

[57] **ABSTRACT**

An ultrasound imaging system is disclosed of the type having a transducer comprising a piezo-electric plate for receiving acoustic energy transmitted through a liquid coupling medium to thereby form an image. The effective aperture of the piezo-electric plate is markedly increased by providing a plurality of hemispherically shaped matching elements disposed in a grid pattern on the acoustic energy receiving surface of the piezo-electric plate. In the preferred inventive embodiment, the hemispherically shaped matching elements are disposed at a distance within the grid-like pattern approximated by the half-wave thickness of the plate, the matching elements being constructed of a material having an acoustic impedance which is substantially equal in value to the square root of the product of the acoustic impedances of the piezo-electric plate and the liquid coupling medium.

6 Claims, 3 Drawing Figures



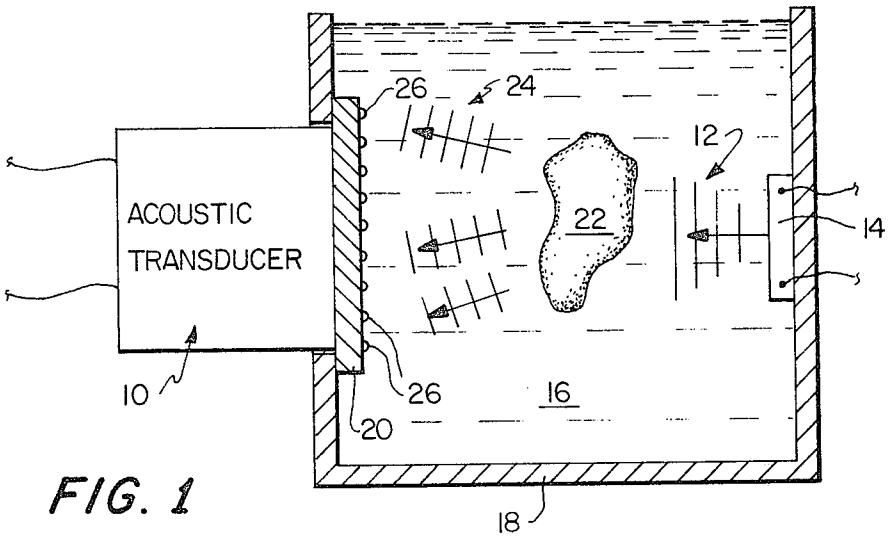


FIG. 1

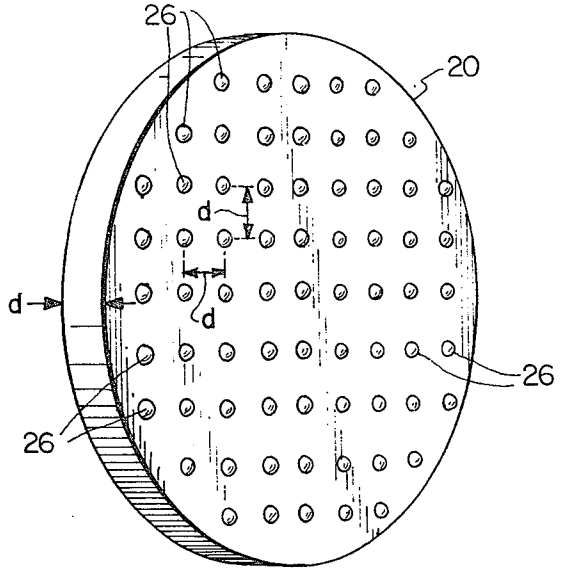


FIG. 2

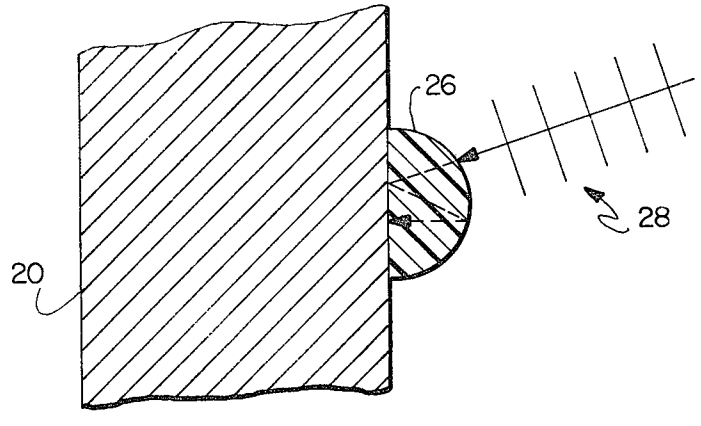


FIG. 3

ULTRASOUND IMAGING SYSTEM UTILIZING SHAPED ACOUSTIC MATCHING ELEMENTS TO INCREASE THE EFFECTIVE APERTURE OF AN ACOUSTIC TRANSDUCER

BACKGROUND OF THE INVENTION

This invention generally relates to ultrasound imaging systems and is particularly concerned with a technique for increasing the so-called effective aperture of the acoustic transducer utilized with such imaging systems.

One of the most severe problems associated with prior art ultrasound imaging systems is the limited and inefficient transfer of acoustic energy between the coupling medium and the transducer element.

For example, in ultrasound imaging systems of the type utilizing a piezo-electric detector such as a quartz plate for receiving acoustic energy transmitted through a liquid coupling medium such as water, acoustical impedance mismatches generally exist as between the energy receiving surface of the piezo-electric plate and the liquid coupling medium, this impedance mismatch being so severe that approximately 80 per cent of the acoustical energy incident upon the energy receiving surface of the piezo-electric plate is reflected back into the liquid coupling medium. Further, the impedance mismatch brings about a very small "effective aperture" of the transducer element in that only acoustic energy incident on the piezo-electric converting surface within a small critical angle is effective to produce an image on the transducer plate. Typically, only sound that is incident on the piezo-electric energy receiving surface at angles within 2° of normal to the surface is effective in obtaining maximum detail and resolution of the system. Sound incident on the piezo-electric surface at angles in excess of this critical value is largely converted into sheer waves within the piezo-electric material and serves to degrade the resolution capability of the system.

These problems are well-known in the art and many attempts have been made to improve the impedance match between the transducer element and the liquid coupling medium to thereby increase the effective aperture of the transducer element. Such prior art approaches to improve the energy coupling feature typically utilize extended matching acoustic impedance layers applied to the piezo-electric surface. While an improved impedance match may result, a serious degradation of the resolving capabilities of the ultrasound imaging system usually is brought about. This is due to the fact that the matching acoustic impedance layers are placed in intimate contact with the piezo-electric transducer surface and serve to couple together adjacent "elements" on the surface with a resultant loss in resolution capability.

SUMMARY OF THE INVENTION

It is thus apparent that a need still exists in the ultrasound imaging art for the provision of a system providing acoustic impedance matching between the transducer element and the liquid coupling medium in a fashion which does not bring about other problems such as loss of resolution capability. It is the primary objective of the instant invention to provide such an improved system.

A further objective of the instant invention concerns the provision of a specially-shaped acoustic energy receiving surface of a piezo-electric transducer element which not only provides acoustic impedance matching, but which further markedly increases the sensitivity of the imaging surface without seriously degrading the resolution capabilities thereof.

Yet another objective of the instant invention concerns the provision of an improved piezo-electric transducer element which can react to incident acoustic energy within a very wide aperture angle.

These objects, as well as others which will become apparent as the description proceeds, are implemented by the instant invention which has particular applicability in an ultrasound imaging system of the type having a transducer such as a piezo-electric plate for receiving acoustic energy transmitted through a liquid coupling medium. In the preferred inventive embodiment, a plurality of hemispherically-shaped matching elements are disposed in a grid pattern on the acoustic energy receiving surface of the piezo-electric plate. The spacing between the hemispherically-shaped matching elements is contemplated to be approximated by the half-wave thickness of the plate itself, this half-wave thickness being the thickness of the plate that produces half-wave resonance at a given frequency of interest of the incident acoustic energy. In this manner, adjacent elements of the piezo-electric plate are effectively decoupled from each other and thus, the resolution capabilities of the system are not seriously degraded. Further, the hemispherically-shaped matching elements are preferably constructed of a material, such as a mixture of copper and epoxy, which has an acoustic impedance which is substantially equal in value to the square root of the product of the acoustic impedances of the piezo-electric plate and the liquid coupling medium. In this manner, an impedance match is provided between the liquid coupling medium and the piezo-electric plate.

It has been found that the utilization of the hemispherically-shaped matching elements in the above manner not only reduces the amount of incident energy that is reflected from the plate back into the liquid coupling medium, but also greatly increases the effective aperture of the transducer element. In this respect, incident acoustic sound energy which arrives at an angle normal to the hemispherical surface of the matching elements is internally reflected within the matching elements and enters the surface of the piezo-electric plate essentially normal to such surface so as to produce a signal in the imaging mode of the plate. Further, it has been found that the provision of the matching elements serves to increase the sensitivity of the piezo-electric plate 4 or 5 times.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be better understood, and further features and advantages thereof will become apparent, from the following detailed description of the preferred inventive embodiment, such description making reference to the appended sheet of drawings, wherein:

FIG. 1 is an elevational view, partially in section, of an ultrasound imaging system utilizing the novel matching elements of the instant invention;

FIG. 2 is a perspective illustration of a piezo-electric transducer plate having disposed thereon the hemispherically-shaped matching elements of the instant invention; and

FIG. 3 is a partially broken away side elevational view of a single hemispherically-shaped matching element disposed on the surface of the piezo-electric transducer plate.

DETAILED DESCRIPTION OF THE PREFERRED INVENTIVE EMBODIMENT

With reference now to FIG. 1 of the application drawings, an exemplary ultrasound imaging system is depicted, which system utilizes the matching elements of the instant invention disposed on the transducer plate. Specifically, the system illustrated is the type wherein an acoustic transducer element generally designated by reference numeral **10** receives acoustic energy generally represented by reference numeral **12** transmitted by a generator **14** through a liquid coupling medium such as water **16** within a tank **18.**

The acoustic transducer **10** is generally of conventional construction and can be of the Sokoloff-tube type, or of any other type such as the Hydrocon-type conversion system, which two basic types are well-described in the literature, complete descriptions of such image conversion tubes being found in U.S. Pat. No. 2,164,125 and in U.S. Pat. No. 3,325,777, respectively, which patent disclosures are incorporated herein by reference. Acoustic transducer **10** typically includes a piezo-electric plate such as quartz plate **20,** again in well-known fashion.

Continuing, an object **22** which is intended to be ultrasonically examined through an ultrasound imaging technique is immersed within liquid **16** and is disposed between the acoustic energy generator **14** and the receiver or acoustic transducer **10.** Sound waves **12** produced by generator **14** impinge upon object **22** and are either suppressed, partially absorbed, refracted or otherwise modified in accordance with the external configuration and/or internal structure and characteristics of object **22** during transmittance therethrough, the acoustic energy then impinging upon the piezo-electric plate **20** as represented by reference numeral **24.** The effect of the acoustic energy impinging upon the piezo-electric plate **20** is to induce electric charges on the rear surface of the piezo-electric plate **20** in the form of an "image", this image then being detected through an image converter tube or the like as above-described within acoustic transducer **10** so that an ultimate visual display of the acoustic image of object **22** is provided. Apart from this basic description of the general operation of the system of FIG. **1,** no further explanations are believed to be necessary due to the well-developed nature of the ultrasound imaging art.

As explained at the outset, not all of the acoustic energy **24** which is incident upon the piezo-electric plate **20** is useful in producing a usable image within the acoustic transducer **10.** Due to mismatch between the impedance of the piezo-electric plate **20** and the liquid coupling medium **16,** a very high percentage of the acoustic energy incident upon the plate **20** is reflected back into the liquid coupling medium **16** without forming a usable image. Further, acoustic energy **24** which is incident upon the piezo-electric plate **20** at an angle greater than the very small "critical angle" of plate **20** cannot be properly utilized to form an image in that such sound is largely converted into sheer waves within the piezo-electric material **20** and serve to actually degrade the resolution capability of the plate **20** and the acoustic transducer **10.**

So as to eliminate these limitations of typical transducers, the instant invention contemplates the provision of a plurality of hemispherically-shaped matching elements **26** disposed in a grid-pattern on the acoustic energy receiving surface of the piezo-electric transducer plate **20.**

Reference is made to FIGS. **2** and **3** of the application drawings wherein the preferred disposition and construction of the matching elements **26** is more clearly illustrated.

As previously explained, the prior art attempts to improve the impedance match between the piezo-electric plate **20** and the liquid coupling medium **16** have generally met with failure due to the fact that such prior art approaches typically utilize extending matching acoustic impedance layers applied in intimate contact with the surface of the plate **20** which resulted in serious degradation of the resolving capabilities of the acoustic transducer element in that adjacent elements on the piezo-electric plate **20** were effectively coupled together with the resultant loss in resolution capability. The provision of the matching elements of the instant invention does not result in a degradation of the resolution ability of the imaging system.

This is the case since the matching elements **26** are disposed in a grid-like pattern on the energy receiving surface of the piezo-electric plate **20** in a spaced-apart relationship with respect to one another so as to mechanically isolate one matching element from an adjacent element. Each element **26** therefore constitutes a resolution element which is recognizable under suitable resolution tests.

In this respect, the particular spacing and disposition of the matching elements **26** on the surface of the piezo-electric plate **20** without a resultant loss in resolution capabilities relies on the principle that when the piezo-electric plate **20** is imaging, the resolution is determined by the ability of the piezo-electric plate **20** to decouple adjacent elements and therefore respond to changes in intensity of the incident acoustic energy over a dimension which is equal to the thickness of the plate that produces half-wave resonance. For example, at a particular frequency of interest, such as 3.58 megahertz, the thickness *d* of the plate **20** that produces half-wave resonance is in the order of 0.3 millimeters. It has been determined by experiments, as well as by theory, that the maximum resolution obtainable on the plate **20** is in the order of such half-wave thickness of the plate, and specifically in this particular instance, is approximately 0.8 of a millimeter. Thus, the matching elements **26** are spaced-apart from one another over a distance which is approximated by the half-wave thickness of the plate so that the matching elements **26** are effectively "de-coupled" from one another.

For the system to be fully effective, the acoustic impedance of the matching elements **26** should be substantially equal in value to the square root of the product of the acoustic impedances of the piezo-electric converting layer or plate **20** and the liquid coupling medium **16.** In this respect, and through suitable experimentation, it has been determined that a particularly suitable material for the matching elements **26** is a mixture of copper and a suitable epoxy, which material additionally lend themselves to fabrication over an extended area of hemispherically-shaped elements, which elements have been constructed to have diameters in the order of 0.6 of a millimeter. The deposition of the

matching elements **26** on the energy receiving surface of piezo-electric plate **20** can be obtained through suitable screening techniques in accordance with known technology.

Reference is now made particularly to the illustration in FIG. 3 of the application drawings wherein a single hemispherical element **26** is shown being disposed on the energy receiving surface of the piezo-electric plate **20,** and wherein the effect of the matching element **26** on incoming incident acoustic energy is diagrammatically illustrated. In this respect, and as previously mentioned, the effective aperture of the piezo-electric plate **20** per se is quite small and typically is of the order of 2°. This effective aperture is markedly increased through the provision of the hemispherically-shaped matching elements **26.** Specifically, and as shown, incident sound energy such as represented by reference numeral **28** which arrives off-axis though at an angle normal to the surface of the hemispherically-shaped matching element **26** will be internally reflected within the matching element and will enter the surface of the piezo-electric plate **20** essentially normal to such surface. Accordingly, and as far as the piezo-electric conversion layer **20** is concerned, the incident acoustic energy **28** constitutes a "normal" incident beam and will produce a signal in the imaging mode. Through experimentation, it has been found that the provision of the hemispherically-shaped matching elements permits sound incident at angles approaching 35° to be effective in producing an image on the piezo-electric plate **20.** As a further advantage, it has been found that the provision of the matching elements serves to increase the sensitivity of the piezo-electric plate **20** some 4 to 5 times, all without seriously degrading the resolution capabilities of the system.

It should be apparent from the foregoing detailed description that the objects set forth hereinabove have been successfully achieved. Moreover, while there has been shown and described a present preferred embodiment of the invention, it is to be distinctly understood that the invention is not limited thereto, but may otherwise variously be embodied and practiced within the scope of the following claims. For example, though the foregoing description has been particularly directed towards an improved configuration of the energy receiving surface of transducers incorporating a plate of piezo-electric material, the hemispherically-shaped matching elements of the invention can also be applied to the surface of other transducer or diaphragm materials as utilized in sound imaging systems, still obtaining the advantages discussed herein. ACCORDINGLY,

What is claimed is:

1. In an ultrasound imaging system having a transducer for receiving acoustic energy transmitted through a liquid coupling medium, the improvement which comprises a plurality of hemispherically-shaped matching elements, said elements being physically separated and spaced apart from one another in a grid pattern on an acoustic energy receiving surface of said transducer to thereby increase the sensitivity and effective aperture of the transducer.

2. The ultrasound imaging system defined in claim **1,** wherein said transducer incorporates an energy receiving plate, said hemispherically-shaped matching elements being disposed in spaced-apart relationship in said grid-like pattern on said plate with the spacing between said elements being approximated by the half-wave thickness of said plate, said half-wave thickness being the thickness of said plate that produces half-wave resonance at a given frequency of the transmitted acoustic energy.

3. The ultrasound imaging system defined in claim **2,** wherein said energy receiving plate is constructed of a piezo-electric material.

4. The ultrasound imaging system defined in claim **3,** wherein said matching elements are constructed of a material having an acoustic impedance which is substantially equal in value to the square root of the product of the acoustic impedances of said piezo-electric plate and said liquid coupling medium, thereby providing an impedance match between the liquid coupling medium and the piezo-electric plate.

5. The ultrasound imaging system defined in claim **4,** wherein the material of said matching elements comprises a mixture of copper and epoxy.

6. The ultrasound imaging system defined in claim **4,** wherein said piezo-electric plate comprises a component of a Sokoloff-tube configuration.

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