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(54) **Ultrasonic transducers.**

(57) An ultrasonic transducer providing a plurality of different focal lengths within a unitary structure and comprising a piezoelectric element 10 having a curved surface having varying or different radii of curvature with respective sections 10a, 10b, 10c, 10d of the surface providing respective different focal lengths $0_1, 0_2, 0_3, 0_4$. Each section of the curved surface can include electrodes 22 in the form of a Fresnel zone pattern to provide focussing in the orthogonal dimension.

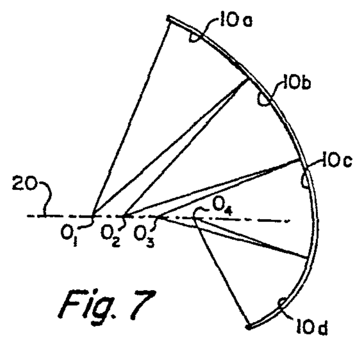

Fig. 7

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ULTRASONIC TRANSDUCERS

This invention relates to ultrasonic transducers and more particularly to a transducer having multiple focal lengths in a single unitary structure.

Ultrasonic transducers, employed for example for medical diagnostic purposes, are known in which the transducer is focussed for an intended focal length. Such transducers generally include a spherically curved ceramic piezoelectric element supported on an acoustic backing material, or a flat piezoelectric element supported on an acoustic backing material with an acoustic lens disposed on the front surface of the flat element to provide the intended focussing. These known transducers are operative for only a single focal length, and a different transducer must be constructed for each focal length of interest.

It is an object of the present invention to be able to provide a plurality of different focal lengths within a single unitary structure.

According to the invention, we propose an ultrasonic transducer comprising:

a piezoelectric element having a curved surface, the surface having a plurality of sections along the length thereof, each having a different focal length;

a rear electrode provided on the rear surface of the piezoelectric element;

a front electrode provided on the front surface of each section of the pieoelectric element; and

means for supporting the piezoelectric element and electrode layers.

The transducer comprises a piezoelectric element having a cylindrical spiral or generally cylindrical spiral surface with respective sections or zones of the cylindrical spiral providing respective different focal lengths. Preferably, the piezoelectric element is a plastic piezoelectric film, such as polyvinylidene fluoride (PVF_2), disposed on a support member providing the cylindrical spiral surface. The sections each have a corresponding focus lying in a common plane disposed transversely to the spiral surface. The curved surface of the spiral provides focussing in one dimension, along the length of the spiral.

Focussing in the orthogonal dimension is provided by a Fresnel zone pattern on the front surface of each section of the piezoelectric film. The zone pattern is formed by electrodes on the front surface of the film extending across the width of the film. The front electrodes of the several sections are electrically connected in series or parallel, or in a series-parallel combination, depending upon the capacitance and reaction required for specific applications. The electrode pattern for each section terminates in a respective electrical terminal for coupling to excitation or reception circuitry. A rear electrode is provided on the back surface of the film, typically in the form of a continuous conductive layer with a common terminal for all sections. The Fresnel pattern can be eliminated and replaced by a continuous electrode for each zone on the front surface of the spiral film in applications where ultrasonic focussing is desired in only one dimension in order to provide a line focus.

Embodiments of the invention are described by way of example, with reference to the drawings, in which:

Figure 1 is a pictorial view of a multiple focus ultrasonic transducer in accordance with the invention;

Figure 2 is a side elevation view of the transducer of Figure 1;

Figure 3 is a front view of the transducer of Figure 1;

Figure 4 is an exploded pictorial view of the piezoelectric film and backing;

Figure 5 is a cutaway pictorial view illustrating the electrode pattern on one section of the spiral surface;

Figure 6 is a side view of an alternative embodiment of the novel transducer employing two piezoelectric elements; and

Figure 7 is a diagrammatic side view of the piezoelectric element illustrating the multiple foci.

Referring to Figures 1 and 2, there is shown an ultrasonic transducer constructed in accordance with the invention, which comprises a piezoelectric film 10 supported on a support or backing 12 of acoustic damping material and having a concave surface 14 of varying radius of curvature and uniform width and length. A filler material 16 for acoustic damping is disposed rearwardly of support 12, the entire assembly being contained within a housing 18.

As seen in Figure 1 and Figure 3, the piezoelectric film 10 is divided into adjacent sections which are formed by strips of substantially constant width along the length, L, of the concave surface 14, each section having a different respective focal length. Referring to Figure 7, section 10a has a focus at 0_1, section 10b has a focus at 0_2, section 10c has a focus at 0_3, and section 10d has a focus at 0_4. The focal points 0_1 to 0_4 lie along an axis 20 which is the optical axis of the transducer. The sections can have continuously increasing radius of curvature to provide part of a true spiral, or each section can have constant or substantially constant radius of curvature to approximate a spiral path.

Each section of the film 10 has a Fresnel zone pattern thereon across the width, w, of the film surface to provide focussing in the width dimension as shown in Figures 1 and 3. Focussing in the longitudinal direction of the spiral is provided by the curved surfaces of the sections. The Fresnel zone pattern for each section is slightly different to that of the others to account for the different focal lengths. The Fresnel pattern for each section is provided by conductive strips 22 formed on the front surface of the film 10, the front electrodes being electrically interconnected to provide an intended capacitance and reactance. A rear electrode 24 is provided on the rear surface of the film 10 in the form of a continuous conductive layer providing a common electrode for the secti.ns.

The Fresnel zone pattern for one section is illustrated in Figure 5. The pattern includes a plurality of electrode area symmetrically disposed about a centre line, each of the electrode areas being of predetermined width and spaced from adjacent electrode areas by a predetermined distance. The centre line of each electrode area lies at a distance d from the centre line of the Fresnel pattern and can be found by

$$d = \pm \left[(n\lambda)(2a + n\lambda)\right]^{1/2} \quad \text{Eq. 1}$$

where n is an integer 0, 1, 2, etc. for each sucessful electode area; a is the mean focal length for the particular section of the curved surface; and

λ is the wavelength per cycle.

The width of each electrode area Δ d can be obtained by substituting n $\pm$ 0.25 for the integer n in equation 1. The centre of each area between the electrode areas can be found by substituting (2n + 1) /2 for the integer n in equation 1.

If the number of electrode areas is relatively small, equation 1 reduces to

$$d = \pm (2an\lambda)^{1/2} \quad \text{Eq. 2}$$

As an example, for a frequency f of 1 MHz, a focal length of 10 centimeters, and a sound velocity v in water of 1.5×10^5 centimeters per second, the wavelength λ is equal to $v/f = (1.5 \times 10^5) / 10^6 = 0.15$ centimeters per cycle. Thus, the centre of the electrode areas in the section under discussion are expressed as follows:

$$d = \pm (2a\lambda)^{1/2}(n)^{1/2} = 1.732\ n^{1/2} \quad \text{Eq. 3}$$

For purposes of the above example, the section is considered as having a constant radius, and therefore constant focal length, throughout its extent. Since the surface is actually a portion of a cylindrical spiral which has a slightly varying focal length throughout its zone length, the location of the electrode areas should be calculated for the mean focal length for the zone. Alternatively, the electrode areas can be calculated separately for the end portions of a zone to accommodate the focal length variations.

For each section of the spiral, the electrode areas are electrically connected in series or parallel, or in a series-parallel combination to provide an intended capcitance to achieve a reactance of predetermined value, typically in the range of 25-50 ohms. Each section has a respective electrical terminal 25 (Figure 5) for connection to electronic circuitry for energizing the transducer for transmission for receiving and processing signals produced in response to received ultrasonic energy. The rear electrode is common to all sections and has a common terminal which serves as the second terminal for all sections. In the illustrated embodiment, the piezoelectric film is polyvinylidene fluoride (PVF_2), and the electrodes are formed of a nickel-chrome alloy. The electrodes are provided on the film in any known manner, such as by vacuum sputtering.

The polyvinylidene fluoride has a broadband frequency response, and therefore the thickness of the film is not as critical as with typical PZT materials which have a much narrower band frequency response. For a frequency constant of about 20 KHz-inches, the film operative at 1 MHz can have a thickness of about 250-500 microns. For a dielectric constant K of 13, the capacitance C for each square centimetres of the electrode area of a Fresnel pattern is

$$C=e' K /t \qquad \text{Eq. 4}$$

where e' is the permittivity of free space (0.088×10^{-12}) and where t is the film thickness in centimetres. For a film thickness of 250 microns, the capacitance C is equal to 46 picofarads per square centimetre. For a reactance X_c of 50 ohms, the capacitance is

$$C= (2\pi f X_c)^{-1} = 3185 \text{ picofarads} \qquad \text{Eq. 5}$$

For each section or zone in which the electrode areas are connected in parallel, the total electrode area is 3185 picofarads/46 picofarads per square centimetres, which equals 69 square centimetres.

In the event that focussing in two orthogonal axes is not needed, the Fresnel pattern can be eliminated, and the front electrode provided by a continuous electrode film formed on each section of the front surface of the piezoelectric material, each front electrode having a respective electrical terminal. In this version, a line focus would be provided by each section of the spiral surface, as distinguished from a point focus provided in the embodiment described above.

Another embodiment is shown in Figure 6 in which a piezoelectric film 10 is supported on a ceramic piezoelectric material 30 such as PZT (lead zirconate titanate). Both piezoelectric materials are disposed in a portion of a cylindrical spiral path, as in the above embodiment. This dual layer structure is supported on an acoustic damping backing material, as in the above embodiment, and can otherwise be similarly housed. In typical fabrication, the PZT material 30 is bent into the spiral configuration while in its plastic state prior to firing, and after firing, it will retain its spiral shape. The piezoelectric film 10 can then be bonded to the PZT material. Front and rear electrodes are provided for each piezoelectric layer, the electrode areas being connected to respective terminals. The Fresnel electrode pattern can be provided for each zone on the front surface of the film, and on the rear surface of the PZT layer, with a common electrode layer interposed between the rear surface of the film and the front surface of the PZT material. Alternatively, each piezoelectric layer can have the Fresnel pattern for each zone on its front surface, and a rear electrode on its rear surface, with an electrically insulating spacer provided between the front electrodes of the PZT material and the rear electrode of the film material to maintain electrical isolation between the two transducers.

The polyvinylidene fluoride film is more effective for ultrasonic reception than for transmission, while the PZT material is superior for transmission rather than reception. Thus, in the composite structure illustrated in Figure 6, the PZT layer is energized with an appropriate driving signal for transmitting ultrasonic energy in a focused manner to an object under study, and the film layer is operative to received energy preferentially focused onto the respective section or zone of the film to generate outpute signals representative of received ultrasonic energy.

The novel transducer finds particular application as an immersion transducer for medical diagnostic purposes. The immersion transducer is placed in a vessel containing water or other liquid, the transducer being spaced from the subject by the interposed liquid. Ultrasonic energy is coupled via the liquid from the transducer to the subject, which is also immersed in the liquid. Alternatively, a thin layer of liquid or gel can be employed to couple the transducer directly to living tissue.

The invention is also useful in other frequency applications. For example, the transducer can be employed for sonar, in which case the transducer dimensions would be appropriately scaled up to accommodate the lower frequencies employed for sonar work. For medical diagnostic purposes, frequencies are typically in the range of 1-10 MHz, while sonar is operative at about 30 KHz.

The scope of the invention is not to be limited except as indicated in the appended claims.

CLAIMS:

1. An ultrasonic transducer comprising:

a piezoelectric element having a curved surface, the surface having a plurality of sections along the length thereof, each having a different focal length;

a rear electrode provided on the rear surface of the piezoelectric element;

a front electrode provided on the front surface of each section of the piezoelectric element; and

means for supporting the piezoelectric element and electrode layers.

2. A transducer according to claim 1, wherein the front electrode for each section includes:

a Fresnel zone pattern of length substantially greater than width on the front surface and disposed along the length of the element.

each section having a Fresnel zone pattern of focal length corresponding to the focal length of the respctive associated section of the curved surface.

3. A transducer according to claim 1, wherein the Fresnel zone pattern for each section of the curved surface is symmetrically disposed about the centre line of the curved surface.

4. A transducer according to claim 1, wherein the piezoelectric element is a piezoelectric film disposed in a path conforming with the shape of the curved surface.

5. A transducer according to claim 4, wherein the piezoelectric film is of polyvinylidene fluoride.

6. A transducer according to claim 2, wherein the Fresnel zone pattern for each section is provided by an array of spaced electrode areas, the array extending across the width of the piezoelectric element.

7. A transducer according to claim 6, wherein the electrode areas of each section are electrically interconnected to provide a predetermined capacitance and reactance.

8. A transducer according to claim 2, wherein the Fresnel zone pattern includes electrode areas, each extending along the longitudinal axis of the curved surface, the pattern extending across the transverse axis, the electrode area being of defined width and spacing for the respective sections.

9. A transducer according to claim 8, wherein the Fresnel zone pattern for each section of the curved surface is of different width and spacing to provide a respective focal length.

10. A transducer according to claim 9, wherein the supporting means includes acoustic damping material.

11. A transducer according to claim 9, wherein the supporting means includes a block of acoustic damping material having a curved on which the piezoelectric element is disposed and conforming with the shape of the piezoelectric element.

12. A transducer according to claim 11, wherein the piezoelectric element has a uniform width.

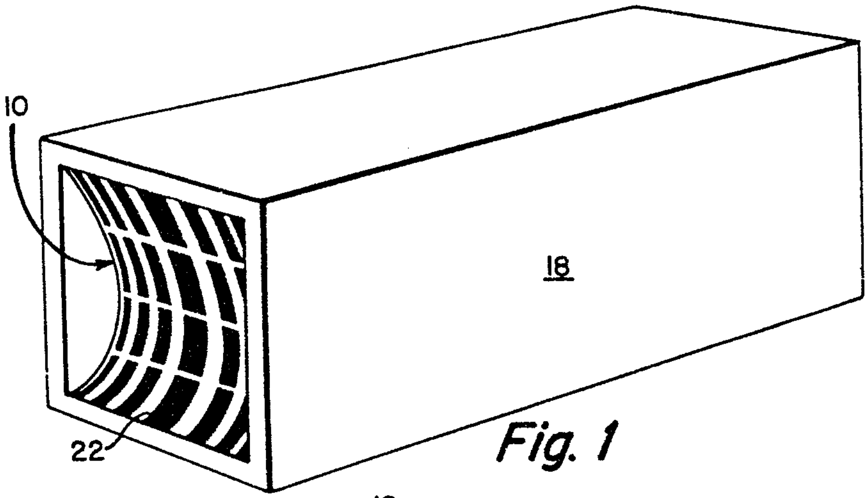

Fig. 1

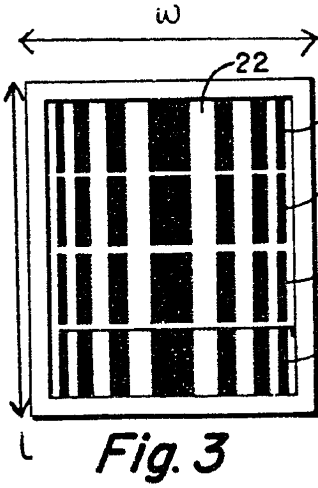

Fig. 3

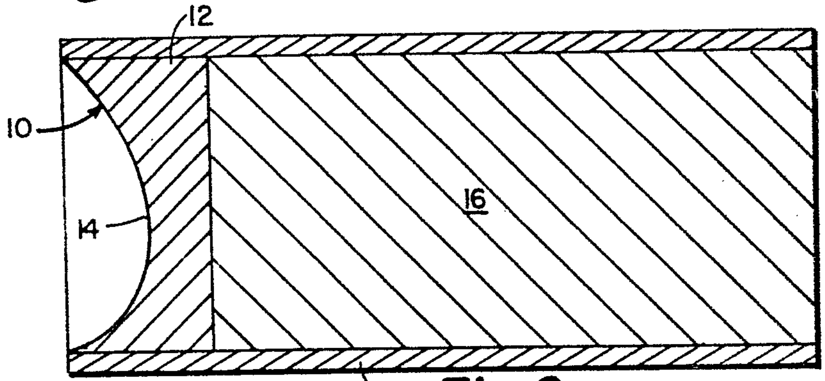

Fig. 2

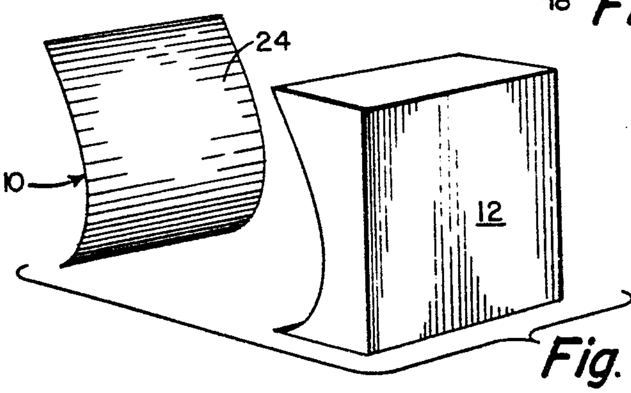

Fig. 4

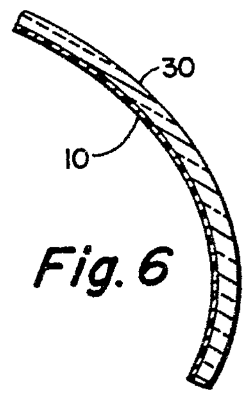

Fig. 6

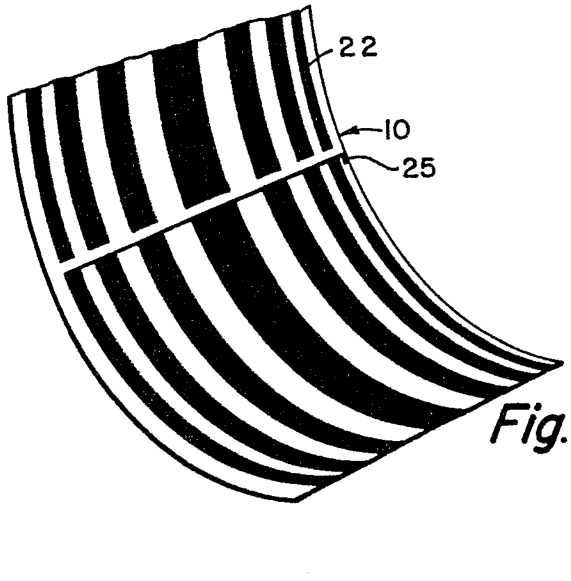

Fig. 5

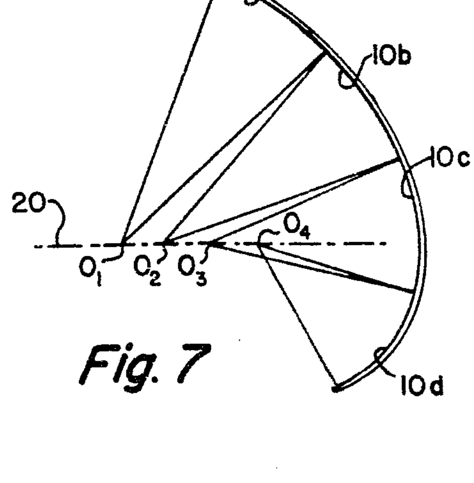

Fig. 7

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EUROPEAN SEARCH REPORT

0134346

Application number

EP 83 30 4934

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int Cl. 3)
X,Y	AU-B- 480 673 (THE COMMONWEALTH OF AUSTRALIA) * Claims 2,3,5 * ---	1	G 10 K 11/32 G 10 K 11/34
Y	FR-A-2 292 978 (ANVAR) * Claims 1,8 * ---	1-3,6, 9,12	
A	EP-A-0 027 542 (TORAY INDUSTRIES INC.) * Abstract; figure 4 * ---	4,5,6	
A	DE-[illegible] 552 643 (HITACHI) * [illegible] 15, lines 1-9; figure 10 * ---	1	
A	US-A-3 924 453 (J.O. CLARK) * Column 2, lines 49-61; figure 5 * ---	1	**TECHNICAL FIELDS SEARCHED (Int. Cl. 3)**
A	FR-A-2 316 608 (SIEMENS AG) -----		G 10 K 11 G 01 N 29

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	09-05-1984	HAASBROEK J.N.

CATEGORY OF CITED DOCUMENTS

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