(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 598 715 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
05.11.1997 Bulletin 1997/45

(21) Application number: **91908273.5**

(22) Date of filing: **24.04.1991**

(51) Int Cl.[6]: **H04R 17/00**, B06B 1/06, G10K 11/32

(86) International application number:
PCT/AU91/00157

(87) International publication number:
WO 91/17637 (14.11.1991 Gazette 1991/26)

(54) **ULTRASONIC TRANSDUCER**

ULTRASCHALLWANDLER

TRANSDUCTEUR A ULTRASONS

(84) Designated Contracting States:
AT BE CH DE DK ES FR GB GR IT LI LU NL SE

(30) Priority: **27.04.1990 AU 9873/90**

(43) Date of publication of application:
01.06.1994 Bulletin 1994/22

(73) Proprietors:
- **COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION Campbell, ACT 2601 (AU)**
- **AGL CONSULTANCY PTY. LTD. North Sydney, NSW 2060 (AU)**

(72) Inventor: **MARTIN, Barry, John**
Guildford, NSW 2161 (AU)

(74) Representative: **Senior, Alan Murray et al**
J.A. KEMP & CO.,
14 South Square,
Gray's Inn
London WC1R 5LX (GB)

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Remarks:
The file contains technical information submitted after the application was filed and not included in this specification

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Description

This invention relates to ultrasonic piezoelectric transducers, processes of constructing an ultrasonic piezoelectric transducer, a system for transmitting ultrasonic vibrations, a system for detecting ultrasonic vibrations, systems for transmitting and detecting ultrasonic vibrations, a method for transmitting ultrasonic vibrations, a method for detecting ultrasonic vibrations and methods for transmitting and detecting ultrasonic vibrations.

Occasionally situations arise that demand the use of an ultrasonic transducer in the 100kHz - 200kHz range with minimal power requirements and operating into air or other gases. The low power requirement rules out a large number of existing transducers - whether their sensitivities are so poor that they need a large bias voltage which is difficult to achieve in a low power D.C. system. For example, piezoelectric ultrasonic transducers (commonly used underwater) operating into air or other gases are typically of low sensitivity or narrow bandwidth. These characteristics result from the immense acoustic impedance mismatch between air or other gases and the transduction materials (the latter being able to create large forces but with only small deflections). Either one puts up with the small deflections (low acoustic output) or one brings the material into a resonant state at one particular frequency. For echo sensing or information transmission applications a single frequency is useless and as broad a range of frequencies as possible is desirable. some low-bias-voltage (30V) electrostatic transducers have been developed but, by and large, these are expensive and time-consuming to produce.

Thus, for example, United States patent no. 3,816,774 describes a curved piezoelectric element which is exemplified by a number of embodiments described with reference to the Figures. The exemplified embodiments fall generally into two classes: those who are clamped at one end and free at the other, and those which are clamped at more than one position and not in a cantilever state. Also described is a transducer of different character which is arranged in a spiral shape and is intended for use as a direct current voltmeter. US 3,816,774 does not describe a piezoelectric transducer which operates at ultrasonic frequencies.

United States patent no. 4,056,742 describes an "electromechanical transducer" comprising a piezoelectric film having a plurality of curved segments wherein each curved segment has an opposite sign of curvature to an adjacent curved segment. The film has surface electrodes deposited thereon, which are separated between adjacent curved segments providing at leat one electrode for each segment. The film is supported by a frame and is also fixed to a series of ribs between each adjacent curved segment. Because of the manner in which the film of the transducer described in US 4,056,742 is fixed to the ribs, the foil is incapable of the large deflection necessary to provide high acoustic output.

European patent application no. 0,002,161 describes a transducer element comprising a film of piezoelectric polymer arranged between electrodes in the form of a thermoformed protuberance, for use in detecting and generating elastic compression waves, for infrared radiation, and for storing electrical energy. EP 0,002,161 discloses that the transducer claimed therein is capable of transmitting or receiving ultrasonic waves in water. However, in common with other prior art piezoelectric transducers, that disclosed and claimed in EP 0,002,161 is characterised by relatively low acoustic output.

United States patent no. 4,578,613 describes an "electro-acoustic device" having at least one piezoelectric diaphragm which, in the rest condition, is maintained in a curved position under mechanical prestress by means of a curved support and/or by means of an elastic support with a non-flat supporting surface. The diaphragm is free to move in one direction over most of its area. It is, however, secured to the curved support at its edges, in order for the diaphragm to be maintained under mechanical prestress. The physical construction of the device described in US 4,578,613 is such that is suffers from the disadvantage of low acoustic output common to other prior art piezoelectric transducers. Further, there is no teaching in US 4,578,613 of how to produce a piezoelectric transducer capable of operating at ultrasonic frequencies.

It is an object of this invention to provide an ultrasonic piezoelectric transducer in which the problems with the prior art are at least alleviated.

The present inventor has discovered that a piezoelectric material having an appropriate profile can be driven in a mode that is referred to in the specification and claims as a dilational mode which is alternatively referred to as a quasi-longitudinal mode. A tentative explanation of what is meant by a transducer being driven in a dilational mode is as follows. When a piezoelectric material having a curved profile is driven it will bulge out when it is lengthened and contract in when it is shortened. Where it is not curved no transverse motion results. Thus, if the material is gently curved but contains no point of inflection and thus no change in the sign of its curvature, it will undergo transverse vibration of the same phase along its whole length. If, on the other hand, the curve includes a point of inflection the transverse displacement changes in phase at this point. If this curvature having the point of inflection also possesses the appropriate radiation geometry there is a resultant effective coupling of piezoelectric excitation to transverse displacements whereby the out of phase transverse vibrations constructively interfere to give high output and when this occurs the piezoelectric material is being driven in a dilational mode. In this way a transducer possessing a high effective radiating area can be designed for ultrasonic frequencies having wavelengths which are of the order of a few millimetres.

According to the present invention there is provided a piezoelectric transducer capable of transmitting and receiving ultrasonic vibrations, comprising a piezoelectric foil operatively associated with support means supporting and tensioning said foil wherein:

> said foil is profiled and tensioned by said support means for form three curved segments each of which has an opposite sign of curvature to an adjacent one of said three curved segments and is not fixed to said support means, and wherein
> said foil is freestanding between each said segment and the segment(s) next to it and is anchored to said support means on either side of said three curved segments.

Preferably the frequency of the ultrasonic vibrations is in the range of from 10kHz - 200kHz.

Typically the frequency range is 12kHz - 160kHz, 80kHz - 120kHz, 95kHz - 105kHz, 15kHz - 60kHz or 15kHz - 30kHz. There may be more than one vibrational peak in the frequency range.

The transducer may be operable in a dilational mode in which the effective coupling of piezoelectric excitation to transverse displacement in the foil causes out-of-phase transverse vibrations to interfere constructively to give high output.

The support means to tension and profile the piezoelectric foil may be adjustable so that the material can be tensioned and profiled so as to generate and/or receive ultrasonic frequencies in a variety of required ultrasonic frequency ranges.

The foil may comprise any material which is capable of transmitting and/or receiving ultrasonic vibrations. Such materials include piezoelectric polymeric materials, plastics and rubber. Advantageously the piezoelectric material comprises a poled polyvinylidene polymer, PVDF, or a copolymer of vinylidene fluoride and trifluoroethylene which may be in the form of a sheet, foil, film or other appropriate piezoelectric form.

According to a desired form said foil is anchored at two points and extends in a curve to one side of an imaginary straight line joining said two points, said curve being in the shape of two humps, forming two of said three curved segments, joined together by a trough between them forming the third curved segments.

In such a case, preferably

$$1.5 \times d_1 \le x \le 23 \times d_1;$$

$$0.5 \times d_1 \le h_l \le 0.9 \times d_1;$$

$$0.5 \times d_1 \le h_r \le 0.9 \times d_1;$$

$$0.1 \times d_1 \le h_{2l} \le 0.2 \times d_1;$$

$$0.1 \times d_1 < h_{2r} \le 0.2 \times d_1;$$

$$0.05 \times d_1 \le d_2 \le 0.2 \times d_1;$$

and

$$0.6 \times d_1 \le d_3 \le 0.8 \times d_1,$$

> where "d_1" is the distance between said two anchor points;
> "x" is the length of the foil between said two anchor points;
> "h_l" is the perpendicular distance from the peak of the first hump to said imaginary line;
> "h_r" is the perpendicular distance from the peak of the second hump to said imaginary line;
> "h_{2l}" is the difference between "h_l" and the perpendicular distance from the bottom of the trough to said imaginary line;
> "h_{2r}" is the difference between "h_r" and the perpendicular distance from the bottom of the trough to said imaginary line;
> "d_2" is the cross-sectional diameter of the tensioning bar in said trough; and
> "d_3" is the distance between the peaks of the humps.

Typically, d_1 = 10mm.

Generally, d_1 = 10mm; x = 20mm; h_r = 7.5mm; h_l = 7.5mm; h_{2l} = 1.5mm;h_{2r} = 1.5mm; d_2 = 1.0mm; and d_3 = 6.9mm.

Typically h_r is about the same (within 0.5mm) or is the same as h_l and h_{2r} is about the same (within 0.5mm) or is the same as h_{2l}.

Advantageously, the foil comprises a poled polyvinylidene foil which is 5μm to 75μm thick, typically 9μm to 35μm thick, more typically 20μm to 25μm thick, and even more typically 25μm thick.

The foil may have at least two electrodes located thereon, typically one electrode on each side of the foil. The electrodes may be the same or different material, typically the same material. Examples of electrode materials are metals such as Au, Pd, Pt, Ti, Zn, Al, Ag, Cu, Sn, Ga, In, Ni, conducting polymers which require doping with doping agents such as iodine, fluorine, alkali metals and their salts, metal carbonates and arsenic halides, include polyacetylene, polyacetylene copolymers, polypyrroles, polyacrylonitriles, polyaromatics, polyanilines, polythiophenes, polycarbazoles, polybetadiketone and polydipropargylamine, polyacenaphthene/N-vinyl heterocyclics with Lewis acids, poly(heteroaromatic vinylenes), polyphthalocyanines, polymer reacted with 1,9-disubstituted phenalene, polycarotenoids, heterocyclic ladder polymers, alternating aromatic and quinonoid sequences, polyisothianaphthene and poly(para-phenylene) sulphide and polymers which do not require doping such as poly(diether-linked bis-0-nitrile), polyacetylene and polydiacetylene with spacer units, poly(perinaphthalene), poly(carbon diselenide), transition metal poly(benzodothiolene), poly(thiophene sulfonates) and acetylene-terminating Schiff base.

Generally, the width of the foil is 1mm - 3500mm, advantageously lmm - 500mm, typically 3mm - 100mm, more typically 4mm - 40mm, preferably 5mm - 20mm and even more preferably 10mm.

Fig. 1 is an exploded perspective view of an ultrasonic piezoelectric transducer of the invention together with a forming block and cross bar;
Fig. 2 is a block diagram of a circuit for detecting ultrasonic signals using an ultrasonic piezoelectric transducer of the invention;
Fig. 3 is a block diagram of a circuit for transmitting ultrasonic signals using an ultrasonic piezoelectric transducer of the invention.
Fig.4 depicts schematically, in block diagram form, a circuit for detecting and transmitting ultrasonic vibrations;
Figs 5(a) and 5(b) are front and side views respectively of the forming block 13 of Fig. 1 with dimensions shown in mm. Fig 5(a) also depicts a cylindrical crossbar 14;
Fig. 6 is a magnified optical projection of an actual transducer foil profile;
Fig. 7 is an exploded perspective view of an alternative ultrasonic piezoelectric transducer of the invention together with a forming block and crossbar;
Fig. 8 is a cross sectional diagram of a piezoelectric material of Fig. 1 or 7;
Fig. 9(a) is a graph of frequency dependence on angle theta as shown for symmetric transverse modes of a piezoelectric foil, not in accordance with the present invention (the sharp increase at about 20 degrees corresponds to a "buckling" of the mode);
Figs. 9(b) depict modes 1 and 3 theta small and theta greater than 20 degrees;
Figs. 9(c) depict a saddle shaped uni-directional piezoelectric material (the arrow in the first diagram of the Figure depicts the active direction);
Figs. 9(d) depict an inverted U - shaped uni-directional piezoelectric material (the arrow in the first diagram of the Figure depicts the active direction);
Fig. 9(e) is a graph of resonance frequency versus length of the piezoelectric material of Fig. 9(d);
Figs. 10 (1), (2), (3) and (4) depict the shapes of piezoelectric materials which were used in Figs. 11 - 14;
Figs. 11(1) - (4) are power output versus frequency curves for a 1x2cm^2, mono-directional, longitudinal PVDF foil (outputs uncorrected for microphone response for shapes (1) - (4) of Fig. 10;
Figs. 12(1) - (4) are power output versus frequency curves for a 1x2cm^2, mono-directional, transverse PVDF foil (outputs uncorrected for microphone response for shapes (1) - (4) of Fig. 10;
Figs. 13(1) - (4) are power output versus frequency curves for a 1x2cm^2, bi-directional, PVDF foil (outputs uncorrected for microphone response for shapes (1) - (4) of Fig. 10; and
Figs. 14(1) - (3) are power output versus frequency curves for a 1x2cm^2 mono-directional, transverse PVDF foil (outputs corrected for microphone response for shapes (1) - (3) of Fig. 10.

BEST MODE AND OTHER MODES FOR CARRYING OUT THE INVENTION

The following describes the construction of an ultrasonic piezoelectric transducer designed to operate at around 100 kHz. The output of this transducer is relatively high (at around 1 Pa/V at 10cm for its working area of 1cm^2) and, compared to most other piezoelectric transducers, it has a broad bandwidth (around 30 kHz between 3dB points). The reception sensitivity will depend on the type of amplifier applied to the transducer, as will the system noise (i.e. using a high input-impedance voltage amplifier will give different characteristics to a low input-impedance transconductance amplifier).

Referring to Fig. 1 a thin PVDF foil 10 with evaporated electrodes 11 and 12 is caused to bend over a forming block 13 having screw holes 25 (left screw hole shown only), by adjustable crossbar 14 - typically of thin, stiff wire - as per Fig. 1. Dimensions of block 13 are shown in mm in Figs. 5(a) and (b). The diameter of bend 15 in foil 10 is governed by the height of crossbar 14 above block 13. The diameter of bend 15 affects the frequency of operation (about 3mm at 100 kHz) as does foil width 16 (about 1cm at 100 kHz). Both of these dimensions also affect the amplitude of vibration (i.e. the transmission and receptive sensitivities). Foil 10 is fastened to block 13 by nylon screws 17 and 18, and washer 21 which is used in conjunction with screw 18, which also serve to bring the foil into contact with two terminals 19 and 20 which make contact with electrodes 11 and 12 respectively. The portions of foil 10 near to screws 17 and 18 may be treated with sodium hydroxide to remove the aluminium electrodes 12 and 11 respectively. This reduces the capacitance in parallel with the working part of foil 10 and improves both reception and transmission characteristics.

The frequency of maximum acoustic output is close to the frequency predicted for a standing wave resonant across foil 10, however any resonance is largely smeared out due to the action of air or other gases imposing a bending resistance on foil 10 which has a low-acoustic-impedance. Holographic investigation of the mode of vibration indicates that most of the membrane movement normal to foil 10 about midway between the centre of bend 15 and tops of the two bends 22 and 23. Figure 6 depicts a magnified optical projection of an actual transducer foil profile. Numbers corresponding to those of Fig. 1 have been added to Fig. 6 where appropriate to facilitate comparison. The edges at no point have any detectable normal motion. Nor does the centerline, beneath crossbar 14. Thus, to stop gross motion of foil 10, it can be supported at the edges at the tops of the bends 22 and 23 by support posts 26 and 27, and 28 and 29 respectively, as depicted in Fig. 1. The entire transducer of Fig. 1 is, except for radiating surfaces 22 and 23, ideally shrouded by a conductor to reduce electromagnetic and acoustic interference. The height of crossbar 14 can be adjusted by screw (moving forming block 13 relative to a body which supports crossbar 14) or simply by hand. Using either method takes a few seconds, and, given the simplicity of the component parts, the entire assembly should be inexpensive to produce.

A similar, but alternative, arrangement to that depicted in Figs. 1, is depicted in Fig. 7. In this latter arrangement, a thin (generally 22μm - 25μm, typically 25μm) PVDF foil 10a with evaporated electrodes 11a and 12a is caused to bend over a plastic forming block 13a having lugs 25a on either side (left side shown only), by adjustable crossbar 14a - typically of thin, stiff wire housed in a plastic sleeve - as per Fig. 7. Dimensions of block 13 are as shown in mm in Figs. 5(a) and (b). The diameter of bend 15a in foil 10a is governed by the height of crossbar 14a above block 13a. The diameter of bend 15a affects the frequency of operation (about 3mm at 100 kHz) as does foil width (approximately corresponding to width 16a of block 13a (about 1cm at 100 kHz). Both of these dimensions also affect the amplitude of vibration (i.e. the transmission and receptive sensitivities). Foil 10a is clamped to block 13a by locating holes 30a (left hand hole shown only) over lugs 25a (left hand lug shown only), placing plastic washers 21a and 21aa over lugs 25a to bring foil 10a into contact with two terminals 19a and 20a which make contact with electrodes 11a and 12a respectively. Foil 10a can be clamped into place about lugs 25a by locating clamping jaws about washers 21a and 21aa.

To stop gross motion of foil 10a, it is supported at the edges at the tops of the bends 22a and 23a by support posts 26a and 27a, and 28a and 29a respectively, as depicted in Fig. 7. The forming block 13a is preferably formed from an insulator. The height of crossbar 14a can be adjusted by hand which can take a few seconds, and, given the simplicity of the component parts, the entire assembly is inexpensive to produce.

The piezoelectric material 10 of Fig. 1 or 10a of Fig. 7 is saddle shaped as depicted in Fig. 8 where d_2 is the cross sectional diameter of crossbar 14 or 14a operatively associated with the piezoelectric material to tension the piezoelectric material, points A and C are points of anchor of the piezoelectric material, x is the length of the profile of the material between points A and C via Point B, d_1 is the distance between points A and C, d_3 is the distance between the tops of the saddle, h_1 is the height of the piezoelectric material to the top of the left hand saddle from a line joining points A and C, h_r is the height of the piezoelectric material to the top of the right hand saddle from a line joining points A and C, h_{2l} is the height of the left hand saddle of the piezoelectric material and h_{2r} is the height of the right hand saddle of the piezoelectric material, and wherein:

d_1 = 10mm; x = 20mm; h_r = 7.5mm; h_1 = 7.5mm; h_{2l} = 1.5mm; h_{2r} = 1.5mm; d_2 = 1.0mm; and d_3 = 6.9mm.

Fig. 2 depicts schematically, in block diagram form, a system 300 for detecting ultrasonic vibrations. System 300 has an ultrasonic piezoelectric transducer 301 of Fig. 1 or 7 and an amplifier 302 linked electrically to transducer 301. Amplifier 302 is linked, also electrically, to filter 303 which in turn is linked electrically to cathode ray oscilloscope 304.

In use, system 300 is located in an atmospheric environment in which ultrasonic waves are required to be detected. Ultrasonic vibrations in the air or other gases cause transducer 301 to vibrate ultrasonically and are converted to ultrasonic electrical signals by transducer 301. The ultrasonic electrical signals are amplified by amplifier 302, filtered by filter 303 and displayed on cathode ray oscilloscope 304.

Fig. 3 depicts schematically, in block diagram form, a system 400 for transmitting ultrasonic vibrations. System 400 has an ultrasonic piezoelectric transducer 401 of Fig. 1 or Fig. 7 and ultrasonic square/sine wave generator 402 or ultrasonic pulse generator 403 linked electrically with transducer 401.

In use, system 400 is located in an atmospheric environment in which ultrasonic waves are required to be transmitted. Ultrasonic electrical signals which are applied to transducer 401 by square/sine wave generator 402 or pulse generator 403 cause transducer 401 to vibrate ultrasonically causing ultrasonic vibrations to be transmitted into the surrounding air or other gases.

Fig. 4 depicts schematically, in block diagram form, a system 500 for detecting and transmitting ultrasonic vibrations. System 500 has an ultrasonic piezoelectric transducer 501 of Fig. 1 or 7 and an amplifier 502 linked electrically to transducer 501 via switch 505. Amplifier 502 is linked, also electrically, to filter 503 which in turn is linked electrically to cathode ray oscilloscope 504. System 500 has an ultrasonic square/sine wave generator 506 or ultrasonic pulse generator 507 linked electrically to transducer 501 via switch 505.

In use, system 500 is located in an atmospheric environment in which ultrasonic waves are required to be detected. Ultrasonic vibrations in the air or other gases cause transducer 501 to vibrate ultrasonically and are converted to ultrasonic electrical signals by transducer 501. The electrical signals pass to amplifier 502 via switch 505 which links transducer 501 and amplifier 502 when system 500 is in the detection mode. The ultrasonic electrical signals are amplified by amplifier 502, filtered by filter 503 and displayed on cathode ray oscilloscope 504. In the transmitting mode ultrasonic electrical signals which are applied to transducer 501 by square/sine wave generator 506 or pulse generator 507 via switch 505 which links transducer 501 and generator 506 or 507, cause transducer 501 to vibrate ultrasonically causing ultrasonic vibrations to be transmitted into the surrounding air or other gases and can pass to reflecting surface 508 from which they are reflected and detected by system 500 in the detection mode.

Two systems 500 each having transducers according to Fig. 1 or 7 as described immediately above may be placed at a distance from one another to alternatively transmit and receive ultrasonic signals to make measurements such as gas flow rate. An alternative system 500 having two transducers each according to Fig. 1 or 7, where the transducers are placed at a distance from one another to alternatively transmit and receive ultrasonic signals to make measurements such as gas flow rate.

EXAMPLE 1

As has been indicated above, a piezoelectric material of the invention has a curvature having three points of inflection and it is thought that provided the curvature also possesses the appropriate radiation geometry there is a resultant effective coupling of piezoelectric excitation to transverse displacements whereby the out of phase transverse vibrations constructively interfere to give high output and when this occurs that the transducer is being driven in a quasi-longitudinal/dilational mode, that is, generating surface motions parallel to the surface of the piezoelectric material. The function of the curvature of the transducer of the invention function is complex in three ways.

These are described below with reference to Figures 9(a) to 9(e), although Figures 9(a) and 9(b) show transducers outside the scope of the invention, but which are useful for understanding it.

1. Where a length resonance is employed the frequency of the resonance increases with increasing curvature, the amount being related to the integral of the curvature along the foil. (Figure 9(a))
2. Where the whole length of the foil is driven in phase, as is usually the case, a complex curvature serves to distribute transverse displacement response associated with the longitudinal dilations unevenly along the foil, the largest displacements being associated with the points of greatest curvature. At each point of inflection in the foil curvature the phase of the displacement reverses. (Phase reversals can also occur when there is no inflection if the curvature is high. This is illustrated in Figure 9 (b).
3. The curved foil is the radiating shape of the transducer.

Figure 9(c) illustrates the combining of these features in a 25μm thick PVDF piezoelectric material about 10mm wide and 20-30mm in length used for gas velocity measurements in domestic gas. The optimum foil to use is the uni-directional one cut with the active direction across the strip since this suppresses the existence of a strong dilational mode in the length direction (however, a bidirectional PVDF could also be used). Were this present it would cause an additional response peak below the desired one giving low frequency undulations to the output. The foil is driven in the width direction at frequencies at and below the first width resonance. This vibration forces a corresponding periodic dilatation along the foil, via Poisson coupling, which is every where in phase. The foil was curved into the shape shown via clamps at each end and a retaining wire across the middle giving an effective radiating area of about 100 mm^2. The two high curvature mounds possess enhanced transverse motion and are in phase. In the depression between them the transverse motion is in opposite phase. The overall shape across the radiator integrates the output to give a strong broadband response around 100 kHz, wavelength = 3 mm. This response is enhanced by the width resonance at about the same frequency.

A second configuration is shown in Figure 9(d), suitable for lower frequency piezoelectric materials, 20 - 50 kHz. In this case a strip of the uni-directional foil was cut along the active direction and the strong dilational resonance along the foil was used as the basis for the piezoelectric material. The foil is clamped in a simple inverted "U" shape and then the curved front of the inverted "U" was slightly flattened with a retaining wire. The optimum output is obtained when the foil is pushed in until the radiating surface was just shon of being flat. At this point the whole radiating surface vibrates in phase. If the foil is made exactly flat a region in the middle appears having reverse phase which destroys the response. The operating frequency was determined by the length of the foil and second, by the final complex curve and the results are illustrated in Fig. 9(e). A secondary effect of the retaining wire was to broaden the frequency response.

EXAMPLE 2

Theories of the propagation of sound in materials are normally continuum-based. However, the thickness of piezoelectric plastic films is typically 10 to 100 microns and therefore much smaller than the wavelengths propagated in the film, and continuum theory is not applicable. The treatment of acoustic wave propagation in thin films is therefore complicated and approximate only, but permits the identification of quasi-longitudinal or dilational waves primarily generating surface motions parallel to the film surface and to transverse waves. These waves can occur as irrotational or divergence-free waves and may also occur as volume waves or surface waves. ["Structure-Borne Sound", Cremer, Heckl & Ungar, Springer-Verlag, Berlin, 1973].

The following experiments in 25µm thick PVDF film cut in 10 x 20mm lengths demonstrate the effect of the foil geometry on the propagation of and interplay between the dilational and transverse waves. Furthermore intercomparison of the propagation spectra for uni-directional PVDF films cut parallel and transverse to the poling direction identify the peaks on the spectra as due to longitudinal or transverse waves.

Comparisons are made for the four configurations (all on 1 x 2cm foils) depicted in Figs. 10(a), 10(b), 10 (c) and 10(d), designated foil configurations (1), (2), (3) and (4) respectively.

Figs. 11 - 14 of configurations (1) to (4) of PVDF film on a 1cm base width establish the transfer of energy between the modes and demonstrate the criticality of shape/the optimization associated with the current piezoelectric material.

Using the terminology of Fig. 8, the overall length x partly determines the frequency, and the ratio h_2/length determines frequency and output.

Variations of up to ± 0.5mm in h_{2l} and h_{2r} can be tolerated but thereafter there is a rapid decrease in output, e.g. ± 1.0mm causes a reduction of 4 in the signal.

The effect of the electrode mass on the transducer output was to decrease the amplitude i.e. the higher the molecular weight/density of the film and the thicker the electrode thickness, the lower is the amplitude of vibration and the output of the transducer, e.g. from Al - Ti - Ag - Au there is a drop off of dB in output.

INDUSTRIAL APPLICABILITY

An ultrasonic piezoelectric transducer of the invention is especially useful in systems for detecting and/or transmitting ultrasonic vibrations in air or other gases including gas for domestic, commercial or industrial use or fluids including water and sea water.

Claims

1. A piezoelectric transducer capable of transmitting and receiving ultrasonic vibrations, comprising a piezoelectric foil (10) operatively associated with support means (13) supporting and tensioning said foil (10) wherein:

said foil (10) is profiled and tensioned by said support means (13) to form three curved segments (22,15,23) each of which has an opposite sign of curvature to an adjacent one of said three curved segments and is not fixed to said support means (13), and wherein
said foil (10) is freestanding between each said segment (22,15,23) and the segment(s) next to it and is anchored to said support means (13) on either side of said three curved segments (22,15,23).

2. The transducer of claim 1 wherein said ultrasonic vibrations have a vibrational peak in the frequency range of 10kHz - 200kHz.

3. The transducer of claim 1 or 2 being operable in a dilational mode in which the effective coupling of piezoelectric excitation to transverse displacement in the foil (10) causes out-of-phase transverse vibrations to interfere constructively to give high output.

4. The transducer of any one of claims 1 to 3, wherein said support means (13) includes support posts (26-29) operatively associated with two (22,23) of said three curved segments (22,15,23) to support said two segments, said two segments (22,23) being of the same sign of curvature.

5. The transducer of any one of claims 1 to 3, wherein said support means (13) includes a support block (13) on which said foil (10) is mounted, said block (13) having support posts (26-29) operatively associated with two (22,23) of said three curved segments (22,15,23) to support said two segments (22,23), said two segments (22,23) being of the same sign of curvature.

6. The transducer of claim 4 or 5, wherein said support posts (26-29) are wedge shaped.

7. The transducer of any one of the preceding claims, including a tensioning bar (14) operatively associated with one of said curved segments (15) to tension the one of said curved segments (15) which is of the opposite sign of curvature to the other two segments (22,23).

8. The transducer of any one of the preceding claims, wherein said foil (10) is anchored to at two points (A,C) and extends in a curve to one side of an imaginary straight line joining said two points, said curve being in the shape of two humps, forming two of said three curved segments, joined together by a trough between them forming the third curved segments.

9. The transducer of claim 8 when dependent on claim 7, wherein:

$$1.5 \times d_1 \leq x \leq 23 \times d_1;$$

$$0.5 \times d_1 \leq h_l \leq 0.9 \times d_1;$$

$$0.5 \times d_1 \leq h_r \leq 0.9 \times d_1;$$

$$0.1 \times d_1 \leq h_{2l} \leq 0.2 \times d_1;$$

$$0.1 \times d_1 \leq h_{2r} \leq 0.2 \times d_1;$$

$$0.05 \times d_1 \leq d_2 \leq 0.2 \times d_1;$$

and

$$0.6 \times d_1 \leq d_3 \leq 0.8 \times d_1,$$

where "d_1" is the distance between said two anchor points (A,C);
"x" is the length of the foil (10) between said two anchor points (A,B);
"h_l" is the perpendicular distance from the peak of the first hump to said imaginary line;
"h_r" is the perpendicular distance from the peak of the second hump to said imaginary line;
"h_{2l}" is the difference between "h_l" and the perpendicular distance from the bottom of the trough (C) to said imaginary line;
"h_{2r}" is the difference between "h_r" and the perpendicular distance from the bottom of the trough (C) to said imaginary line;
"d_2" is the cross-sectional diameter of the tensioning bar (14) in said trough; and
"d_3" is the distance between the peaks of the humps.

10. The transducer of claim 9, wherein:
d_1 = 10mm

11. The transducer of claim 10, wherein:

x = 20mm;
h_l = 7.5mm;
h_r = 7.5mm;
h_{2l} = 1.5mm;
h_{2r} = 1.5mm;
d_2 = 1.0mm;
d_3 = 6.9mm.

12. The transducer of any one of the preceding claims, wherein said foil (10) comprises a poled polyvinylidene polymer or a poled copolymer of vinylidene fluoride and trifluoroethylene.

13. The transducer of claim 12, wherein said foil (10) comprises a poled polyvinylidene polymer foil.

14. The transducer of claim 13, wherein said foil (10) is in the range of 9µm to 35µm thick.

15. The transducer of claim 14, wherein said foil (10) is 25µm thick.

16. The transducer of any one of the preceding claims, wherein the width of said foil (10) is in the range of lmm - 500mm.

17. The transducer of 16, wherein the width of said foil (10) is in the range of 5mm - 20mm.

18. The transducer of claim 17, wherein the width of said foil (10) is 10mm.

19. The transducer of any one of the preceding claims, wherein said ultrasonic vibrations have a vibrational peak in the frequency range of 80kHz - 120kHz.

20. The transducer of any one of claims 1-18, wherein said ultrasonic vibrations have a vibrational peak in the frequency range of 15kHz - 60kHz.

21. The transducer of claim 20, wherein said ultrasonic vibrations have a vibrational peak in the frequency range 15kHz - 30kHz.

Patentansprüche

1. Piezoelektrischer Wandler, welcher in der Lage ist, Ultraschallschwingungen auszusenden und zu empfangen, und welcher eine piezoelektrische Folie (10) umfaßt, der funktionell mit Stützmitteln (13) zusammenwirkt, welche diese Folie (10) stützen und spannen, wobei:

diese Folie (10) durch die Stützmittel (13) in Form gebracht und gespannt wird, um drei gekrümmte Abschnitte (22, 15, 23) zu bilden, von denen ein jeder eine Krümmung mit einem Vorzeichen aufweist, welches dem des benachbarten Abschnitts entgegengesetzt ist, und an diesen Stützmitteln befestigt ist, und wobei
die Folie (10) zwischen einem jeden der Abschnitte (22, 15, 23) und dem bzw. den nächstliegenden Abschnitte freisteht, und dabei an den Stützmitteln (13) auf einer jeden Seite der drei gekrümmten Abschnitte (22, 15, 23) verankert ist.

2. Wandler nach Anspruch 1, wobei die Ultraschallschwingungen ein Schwingungsmaximum im Frequenzbereich von 10 kHz bis 200 kHz aufweisen.

3. Wandler nach Anspruch 1 oder 2, welcher in einer Ausdehnungsbetriebsart mit betreibbar ist, bei welcher die effektive Kopplung zwischen piezoelektrischer Erregung und transversaler Verschiebung in der Folie (10) gegenphasige transversale Schwingungen dazu bringt, konstruktiv zu interferieren, um eine hohe Ausgabe zu erzielen.

4. Wandler nach einem der Ansprüche 1 bis 3, wobei die Stützmittel (13) Stützpfosten (26 - 29) umfassen, welche funktionell mit zwei (22, 23) der drei gekrümmten Abschnitte (22, 15, 23) zusammenwirken, um die beiden Abschnitte zu stützen, wobei die zwei Abschnitte (22, 23) eine Krümmung mit demselben Vorzeichen aufweisen.

5. Wandler nach einem der Ansprüche 1 bis 3, wobei die Stützmittel (13) einen Stützblock (13) umfassen, auf welchem die Folie (10) aufgesetzt ist, wobei der Block (13) Stützpfosten (26 - 29) umfaßt, welche funktionell mit zwei (22, 23) der drei gekrümmten Abschnitte (22, 15, 23) zusammenwirken, um die beiden Abschnitte (22, 23) zu stützen, wobei die beiden Abschnitte (22, 23) eine Krümmung mit demselben Vorzeichen aufweisen.

6. Wandler nach Anspruch 4 oder 5, wobei die Stützpfosten (26 - 29) keilförmig sind.

7. Wandler nach einem der vorhergehenden Ansprüche, welcher einen Spannstift (14) umfaßt, der funktionell mit einem der gekrümmten Abschnitte (15) zusammenwirkt, um denjenigen der gekrümmten Abschnitte (15) zu spannen, welcher eine Krümmung mit einem zur Krümmung der beiden anderen Abschnitte (22, 23) entgegengesetzten Vorzeichen aufweist.

8. Wandler nach einem der vorhergehenden Ansprüche, wobei die Folie (10) an zwei Punkten (A, C) verankert ist und sich in einer Kurve zu einer Seite einer gedachten geraden Linie hin erstreckt, welche die beiden Punkte verbindet, wobei die Kurve in Gestalt zweier Höcker ausgeführt ist, welche zwei der drei gekrümmten Abschnitte bilden und über ein dazwischenliegendes Tal verbunden sind, welches den dritten gekrümmten Abschnitt bildet.

9. Wandler nach Anspruch 8, soweit von Anspruch 7 abhängig, wobei:

$$1.5 \text{ x } d_1 \;\; x \;\; 23 \text{ x } d_1;$$

$$0.5 \text{ x } d_1 \;\; h_l \;\; 0.9 \text{ x } d_1;$$

$$0.5 \text{ x } d_1 \;\; h_r \;\; 0.9 \text{ x } d_1;$$

$$0.1 \text{ x } d_1 \;\; h_{2l} \;\; 0.2 \text{ x } d_1;$$

$$0.1 \text{ x } d_1 \;\; h_{2r} \;\; 0.2 \text{ x } d_1;$$

$$0.05 \text{ x } d_1 \;\; d_2 \;\; 0.2 \text{ x } d_1;$$

und

$$0.6 \text{ x } d_1 \;\; d_3 \;\; 0.8 \text{ x } d_1;$$

wobei

"d_1" der Abstand zwischen den beiden Ankerpunkten (A, C) ist;

"x" die Länge der Folie (10) zwischen den beiden Ankerpunkten (A, B) ist;

"h_l" der senkrechte Abstand vom Scheitel des ersten Höckers bis zu der gedachten Linie;

"h_r" der senkrechte Abstand vom Scheitel des zweiten Höckers zu der gedachten Linie;

"h_{2l}" der Unterschied zwischen "h_l" und dem senkrechten Abstand vom tiefsten Punkt des Tales (C) zu der gedachten Linie;

"h_{2r}" die Differenz zwischen "h_r" und dem senkrechten Abstand vom tiefsten Punkt des Tales (C) zu der gedachten Linie;

"d_2" der Querschnittsdurchmesser des Spannstifts (14) in diesem Tal ist; und

"d_3" der Abstand zwischen den beiden Scheiteln der Höcker ist.

10. Wandler nach Anspruch 1, wobei:
d_1 = 10 mm.

11. Wandler nach Anspruch 10, wobei:

x = 20 mm;
h_l = 7.5 mm;
h_r = 7.5 mm;
h_{2l} = 1.5 mm;
h_{2r} = 1.5 mm;
d_2 = 1.0 mm;
d_3 = 6.9 mm.

12. Wandler nach einem der vorhergehenden Ansprüche, wobei diese Folie (10) ein polarisiertes Polyvinyliden-Polymer oder ein polarisiertes Copolymer des Vinyliden-Fluorids und des Trifluoroethylens umfaßt.

13. Wandler nach Anspruch 12, wobei die Folie (10) eine polarisierte Polyvinyliden-Polymerfolie umfaßt.

14. Wandler nach Anspruch 13, wobei die Folie (10) zwischen 9 m und 35 m dick ist.

15. Wandler nach Anspruch 14, wobei die Folie (10) 25 m dick ist.

16. Wandler nach einem der vorhergehenden Ansprüche, wobei die Breite der Folie (10) im Bereich zwischen 1 mm bis 500 mm liegt.

17. Wandler nach Anspruch 16, wobei die Breite der Folie (10) im Bereich zwischen 5 mm bis 20 mm liegt.

18. Wandler nach Anspruch 17, wobei die Breite der Folie (10) 10 mm beträgt.

19. Wandler nach einem der vorhergehenden Ansprüche, wobei die Ultraschallschwingungen ein Schwingungsmaximum im Frequenzbereich von 80 kHz bis 120 kHz aufweisen.

20. Wandler nach einem der Ansprüche 1 bis 18, wobei die Ultraschallschwingungen ein Schwingungsmaximum im Frequenzbereich zwischen 15 kHz und 60 kHz aufweisen.

21. Wandler nach Anspruch 20, wobei die Ultraschallschwingungen ein Schwingungsmaximum im Frequenzbereich von 15 kHz bis 30 kHz aufweisen.

Revendications

1. Un transducteur piézo-électrique capable d'émettre et de recevoir des vibrations ultrasonores, comprenant une feuille piézo-électrique (10) associée de manière opérationnelle à des moyens de support (13) portant et tendant ladite feuille (10), dans lequel :

ladite feuille (10) est profilée et tendue par lesdits moyens de support (13) afin de former trois segments courbes (22, 15, 23) dont chacun présente un signe de courbure opposé à un segment adjacent parmi lesdits trois segments courbes et n'est pas fixé audit moyen de support (13), et dans lequel

ladite feuille (10) est placée librement entre chacun desdits segments (22, 15, 23) et le ou les segments près de celui-ci et est fixée auxdits moyens de support (13) sur chaque côté desdits trois segments courbes (22, 15, 23).

2. Le transducteur de la revendication 1, dans lequel lesdites vibrations ultrasonores présentent un pic de vibration dans la gamme de fréquences de 10 kHz à 200 kHz.

3. Le transducteur de la revendication 1 ou 2 qui est actionnable dans un mode de dilatation dans lequel le couplage effectif de l'excitation piézo-électrique au déplacement transversal de la feuille (10) amène des vibrations transversales déphasées à interférer par construction afin de donner un signal de sortie élevé.

4. Le transducteur d'une quelconque des revendications 1 à 3, dans lequel lesdits moyens de support (13) comprennent des montants de support (26 à 29) associés de manière opérationnelle avec deux (22, 23) desdits trois segments courbes (22, 15, 23) afin de supporter lesdits deux segments, ces deux segments (22, 23) étant du même signe de courbure.

5. Le transducteur d'une quelconque des revendications 1 à 3, dans lequel lesdits moyens de support (13) comprennent un bloc de support (13) sur lequel est montée ladite feuille (10), ledit bloc (13) présentant des montants de support (26 à 29) associés de manière opérationnelle avec deux (22, 23) desdits trois segments courbes (22, 15, 23) afin de supporter lesdits deux segments (22, 23), lesdits deux segments (22, 23) étant du même signe de courbure.

6. Le transducteur de la revendication 4 ou 5, dans lequel lesdits montants de support (26 à 29) sont en forme de coin.

7. Le transducteur d'une quelconque des revendications précédentes, comprenant une barre de tension (14) associée de manière opérationnelle à l'un desdits segments courbes (15) afin de tendre celui desdits segments courbes (15) qui se trouve du signe de courbure opposé aux deux autres segments (22, 23).

8. Le transducteur d'une quelconque des revendications précédentes, dans lequel ladite feuille (10) est fixée au niveau de deux points (A, C) et s'étend en une courbe à un côté d'une ligne droite imaginaire joignant lesdits deux points, ladite courbe présentant la forme de deux arcs, en délimitant deux desdits trois segments courbes, réunis ensemble par un creux intermédiaire formant le troisième segment courbe.

9. Le transducteur de la revendication 8 lorsqu'elle dépend de la revendication 7, dans lequel :

$$1{,}5 \times d_1 \leq x \leq 23 \times d_1 \ ;$$

$$0{,}5 \times d_1 \leq h_l \leq 0{,}9 \times d_1 \ ;$$

$$0{,}5 \times d_1 \leq h_r \leq 0{,}9 \times d_1 \ ;$$

$$0{,}1 \times d_1 \leq h_{2\ell} \leq 0{,}2 \times d_1 \ ;$$

$$0{,}1 \times d_1 \leq h_{2r} \leq 0{,}2 \times d_1 \ ;$$

$$0{,}05 \times d_1 \leq d_2 \leq 0{,}2 \times d_1 \ ;$$

et

$$0{,}6 \times d_1 \leq d_3 \leq 0{,}8 \times d_1,$$

où "d_1" est la distance entre lesdits deux points de fixation (A, C) ;

"x" est la longueur de la feuille (10) entre lesdits deux points de fixation (A, B) ;

"h_ℓ" est la distance perpendiculaire entre le sommet du premier arc et ladite ligne imaginaire ;

"h_r" est la distance perpendiculaire entre le sommet du second arc et ladite ligne imaginaire ;

"$h_{2\ell}$" est la différence entre "h_ℓ" et la distance perpendiculaire entre le fond du creux (C) et ladite ligne imaginaire ;

"h_{2r}" est la différence entre "h_r" et la distance perpendiculaire entre le fond du creux (C) et ladite ligne imaginaire ;

"d_2" est le diamètre de section droite de la barre de tension (14) dans ledit creux ; et

"d_3" est la distance entre les sommets des arcs.

10. Le transducteur de la revendication 9, dans lequel :
d_1 = 10 mm

11. Le transducteur de la revendication 10, dans lequel :
x = 20 mm ;
h_ℓ = 7,5 mm ;
h_r = 7,5 mm ;
$h_{2\ell}$ = 1,5 mm ;
h_{2r} = 1,5 mm ;
d_2 = 1,0 mm ; et
d_3 = 6,9 mm.

12. Le transducteur d'une quelconque des revendications précédentes, dans lequel ladite feuille (10) est formée d'un polymère polaire de polyvinylidène ou d'un copolymère polaire de fluorure de vinylidène et de trifluoroéthylène.

13. Le transducteur de la revendication 12, dans lequel ladite feuille (10) est formée d'une feuille de polymère polaire de polyvinylidène.

14. Le transducteur de la revendication 13, dans lequel ladite feuille (10) présente une épaisseur dans la gamme de 9 µm à 35 µm.

15. Le transducteur de la revendication 14, dans lequel ladite feuille (10) présente une épaisseur de 25 µm.

16. Le transducteur d'une quelconque des revendications précédentes, dans lequel la largeur de ladite feuille (10) est dans la gamme de 1 mm à 500 mm.

17. Le transducteur de la revendication 16, dans lequel la largeur de ladite feuille (10) est dans la gamme de 5 mm à 20 mm.

18. Le transducteur de la revendication 17, dans lequel la largeur de ladite feuille (10) est de 10 mm.

19. Le transducteur d'une quelconque des revendications précédentes dans lequel lesdites vibrations ultrasonores présentent un pic de vibration dans la gamme de fréquences de 80 kHz à 120 kHz.

20. Le transducteur d'une quelconque des revendications 1 à 18, dans lequel lesdites vibrations ultrasonores présentent un pic de vibration dans la gamme de fréquences de 15 kHz à 60 kHz.

21. Le transducteur de la revendication 20, dans lequel lesdites vibrations ultrasonores présentent un pic de vibration dans la gamme de fréquences de 15 kHz à 30 kHz.

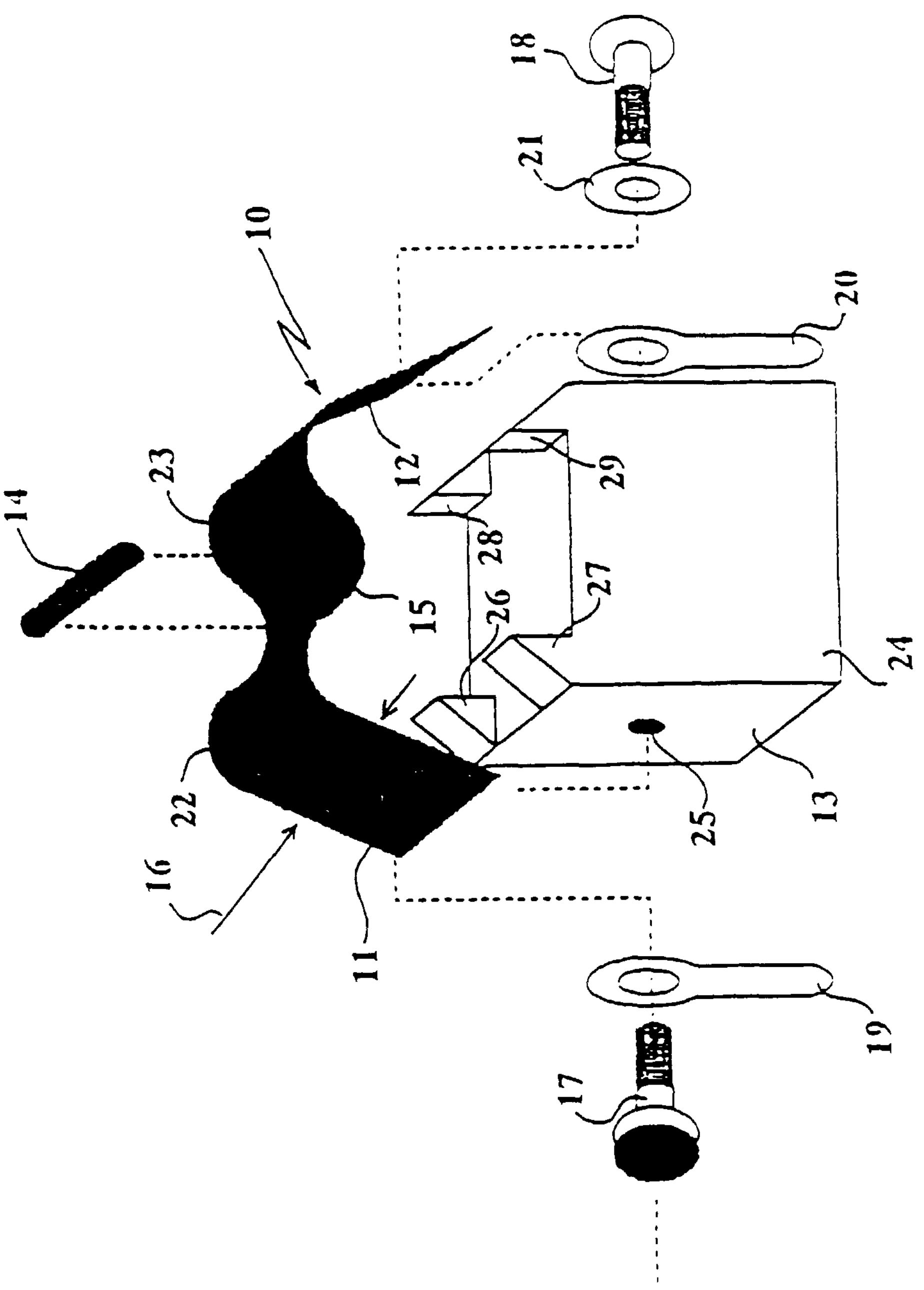


Figure 1

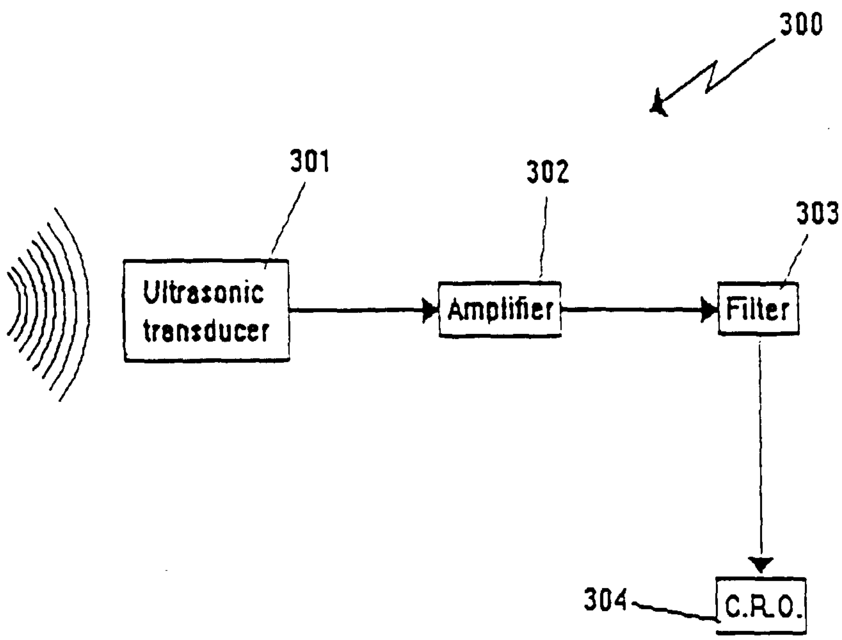

300
301
302
303
Ultrasonic transducer
Amplifier
Filter
304
C.R.O.

Figure 2

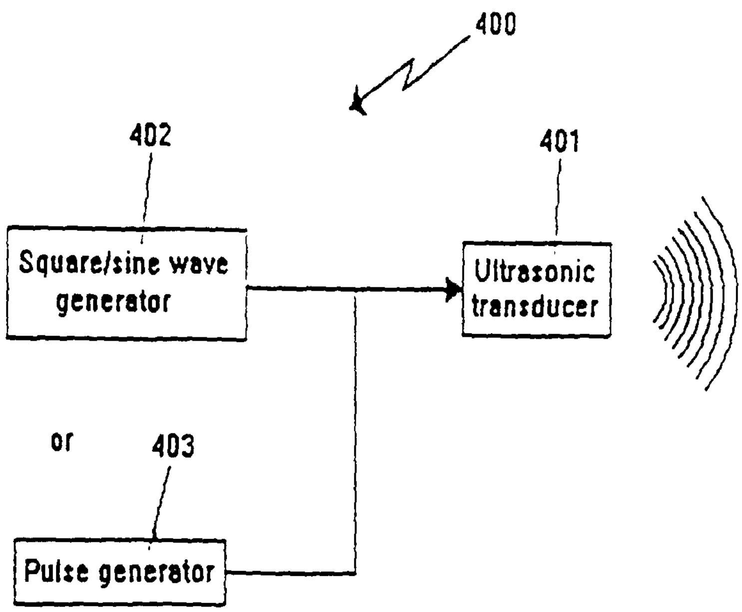

400
402
401
Square/sine wave generator
Ultrasonic transducer
or
403
Pulse generator

Figure 3

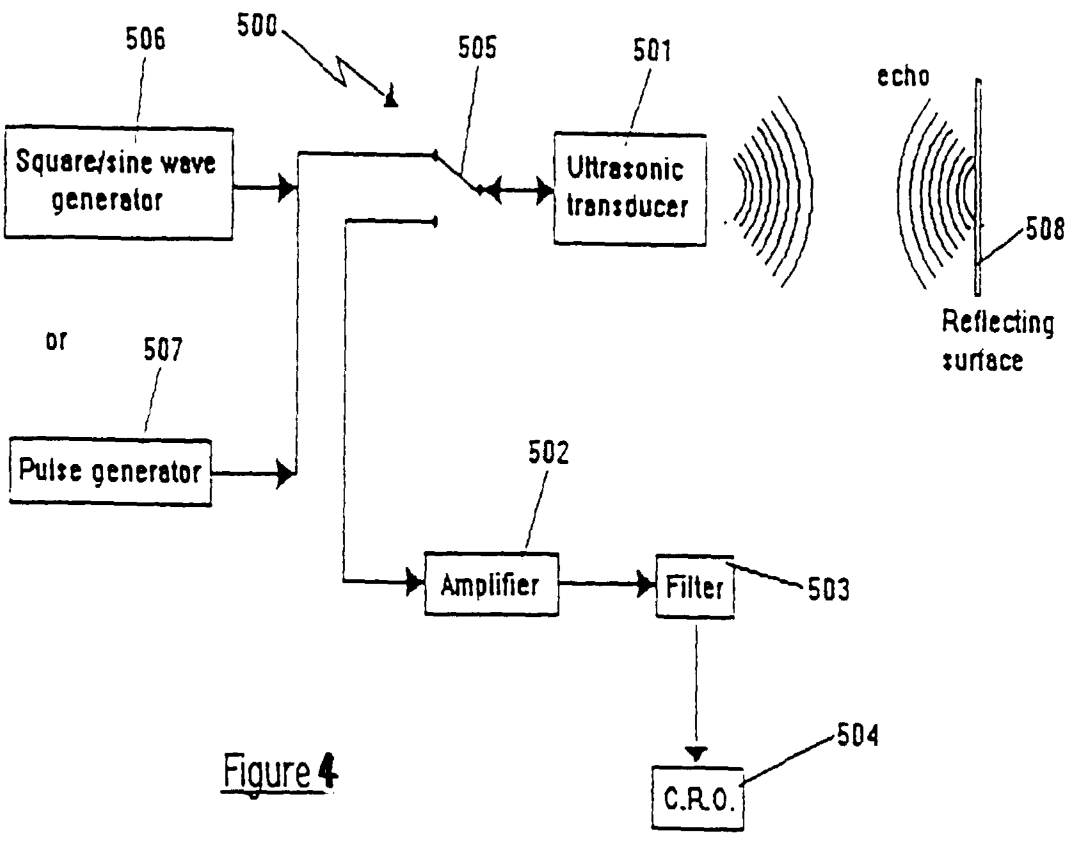

506
500
505
501
echo
Square/sine wave generator
Ultrasonic transducer
508
Reflecting surface
or
507
Pulse generator
502
Amplifier
Filter
503
504
C.R.O.

Figure 4

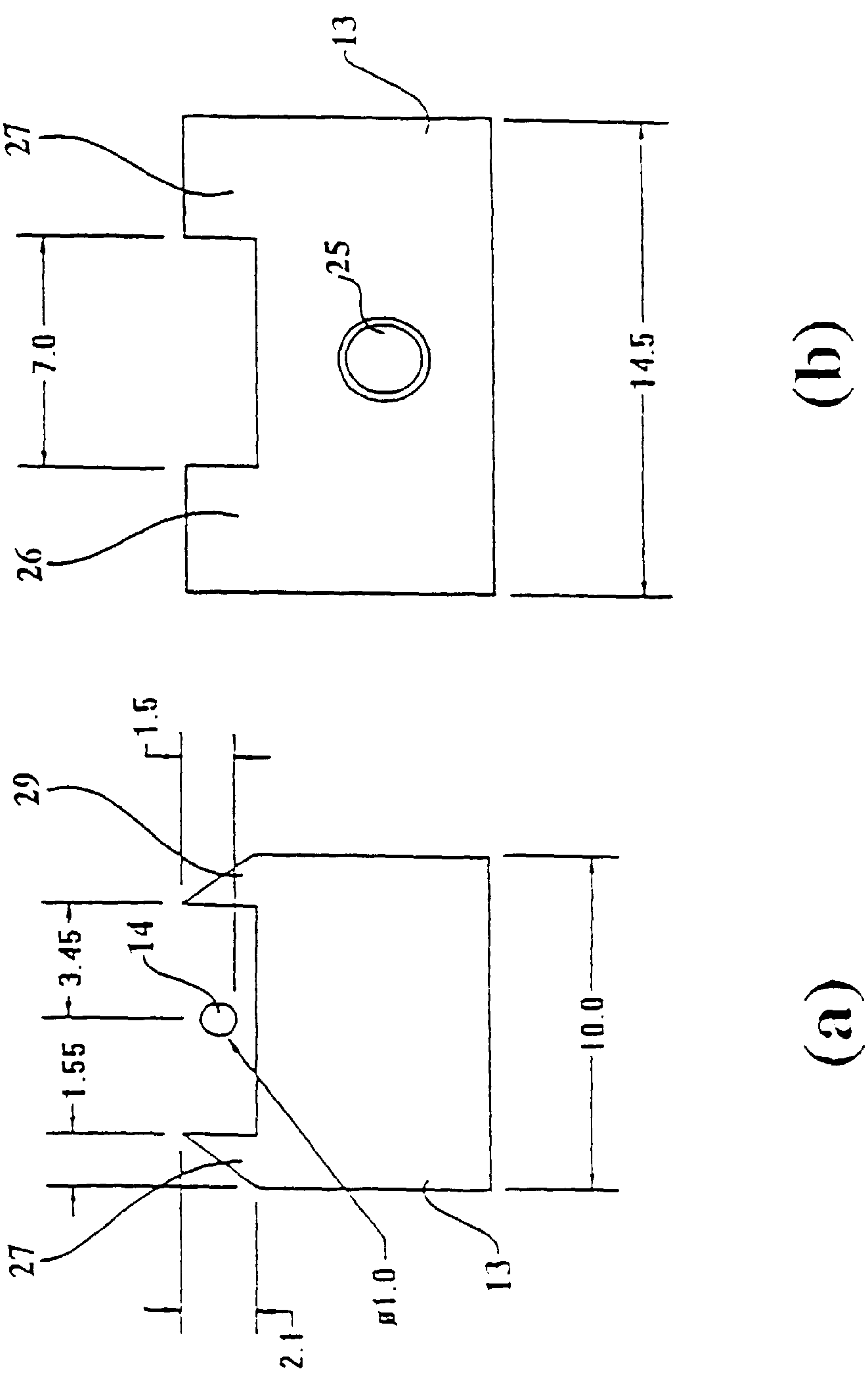


Figure 5

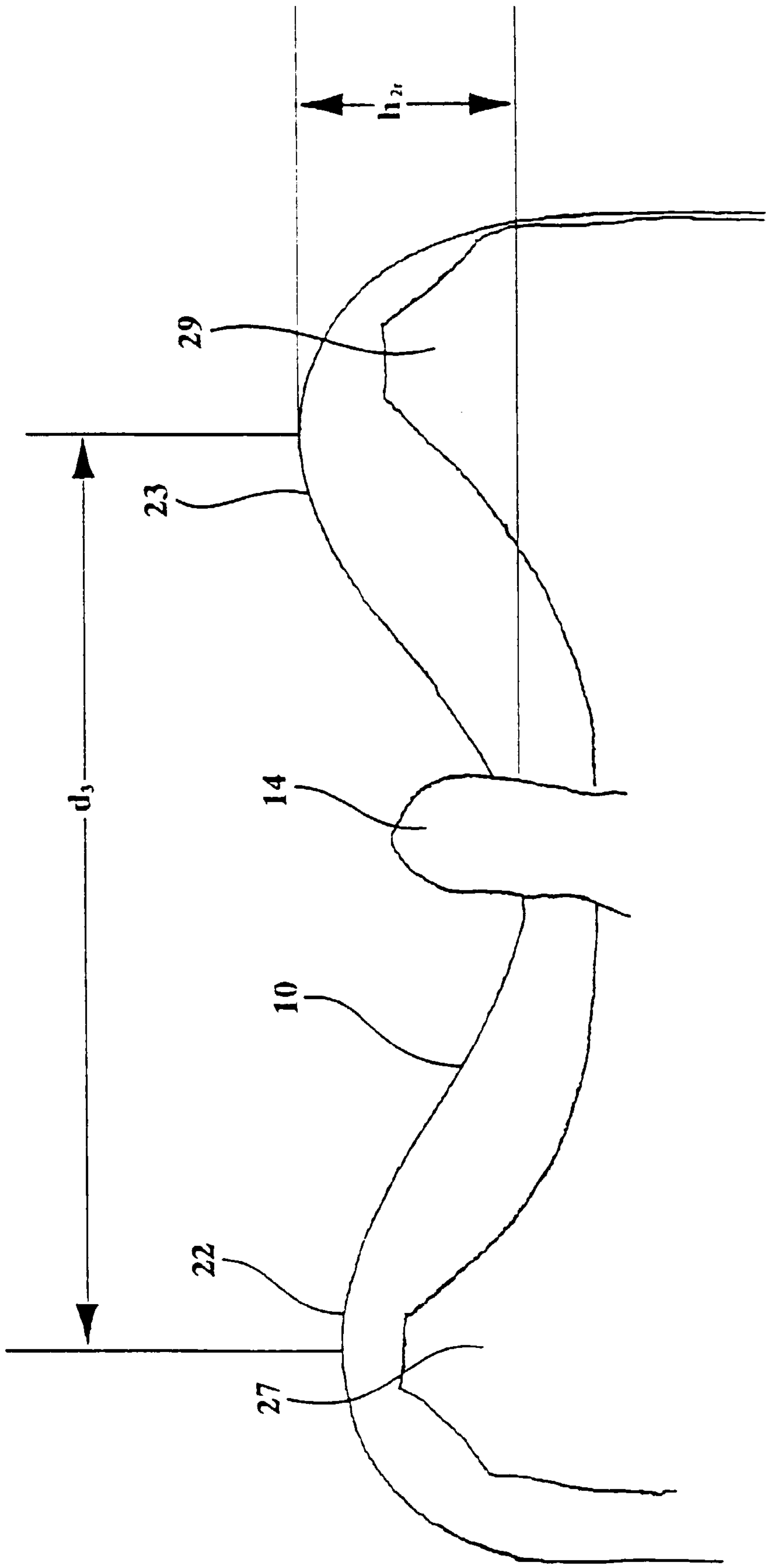


Figure 6

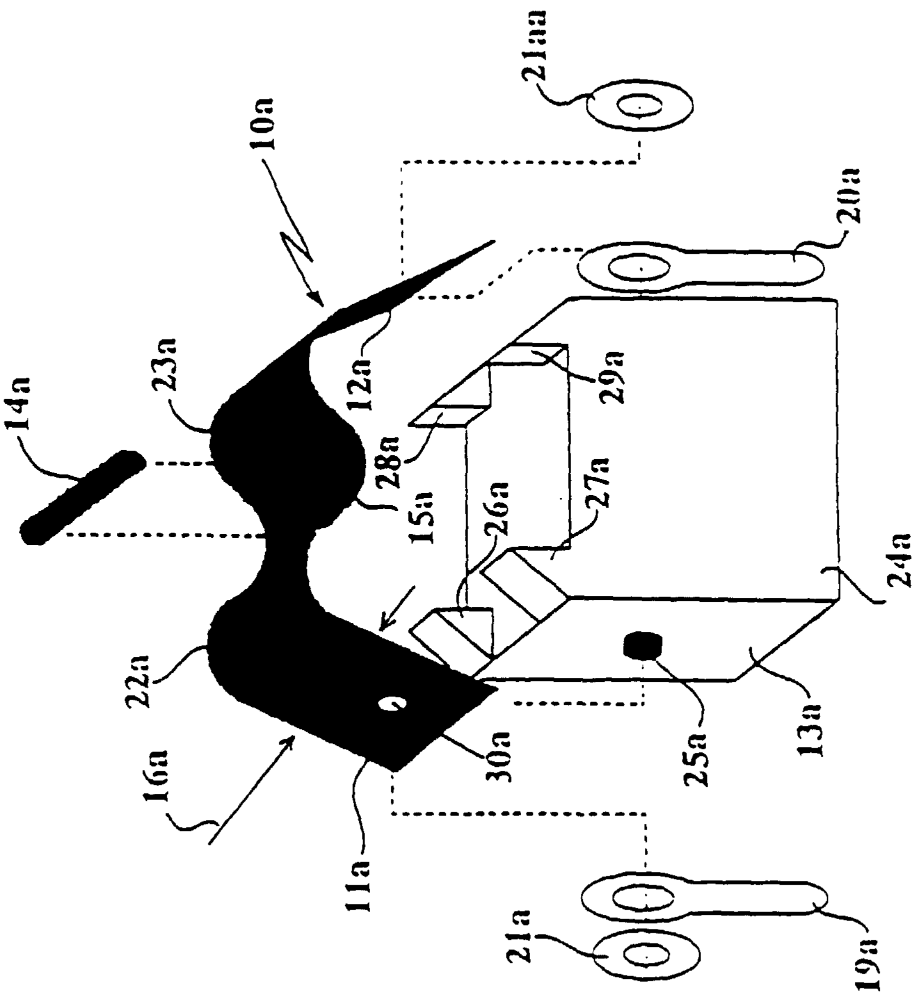

10a
14a
23a
12a
22a
16a
11a
30a
25a
13a
24a
27a
26a
15a
28a
29a
20a
21aa
21a
19a

Figure 7

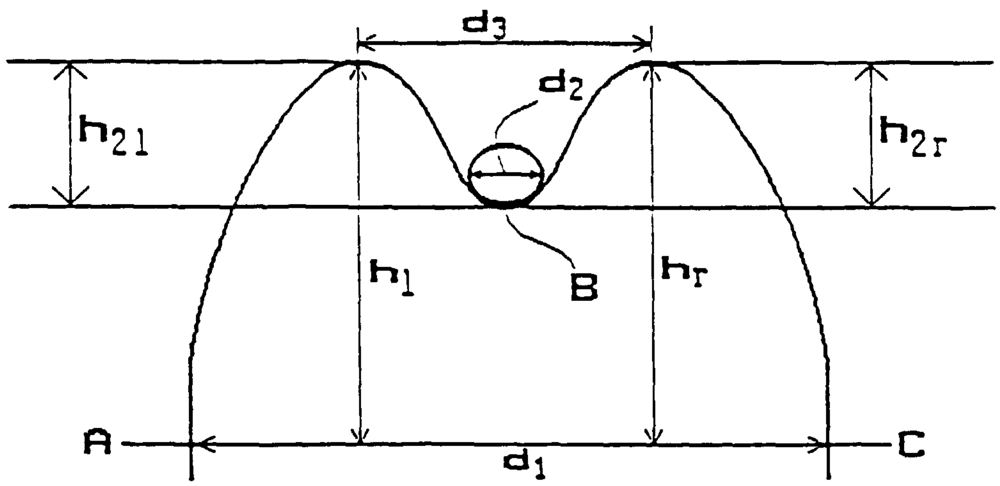


Figure 8

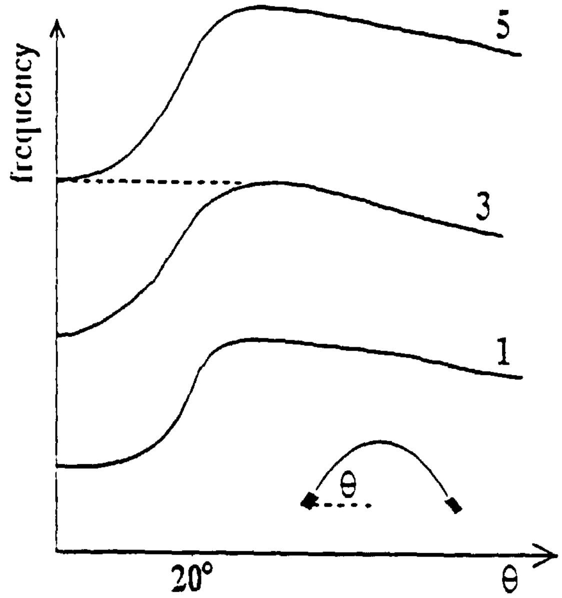


Figure 9 (a)

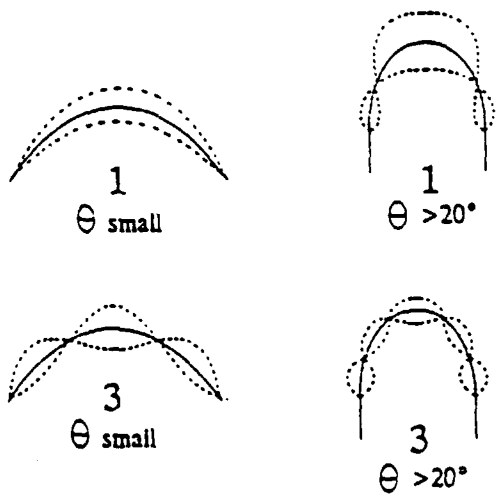


Figure 9 (b)

Figure 9 (c)

Figure 9 (d)

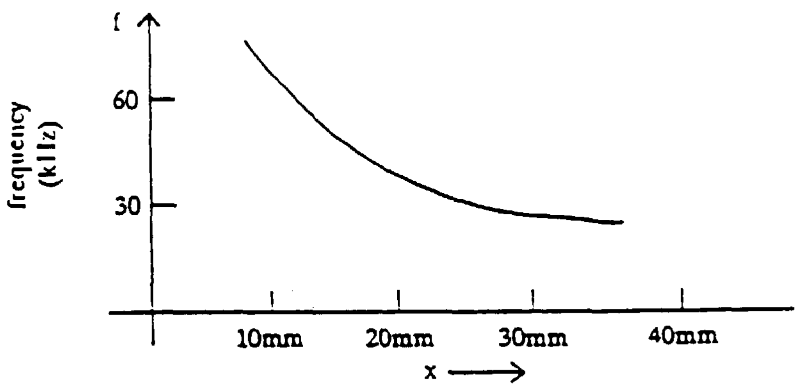


Figure 9 (e)

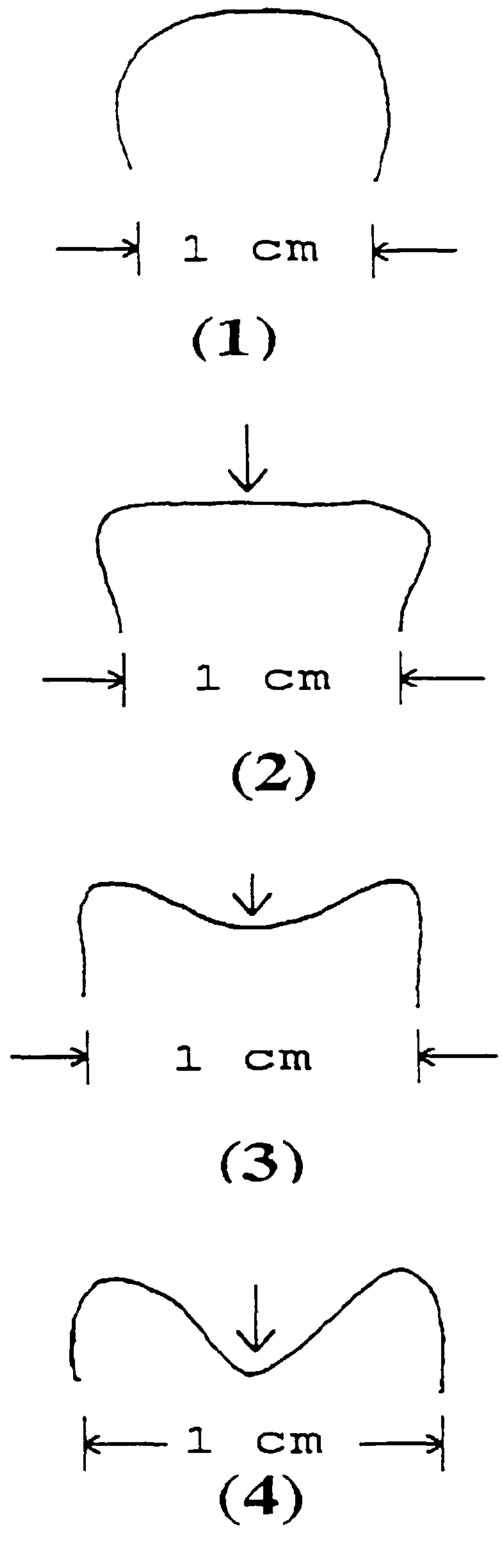


Figure 10

Figure 11

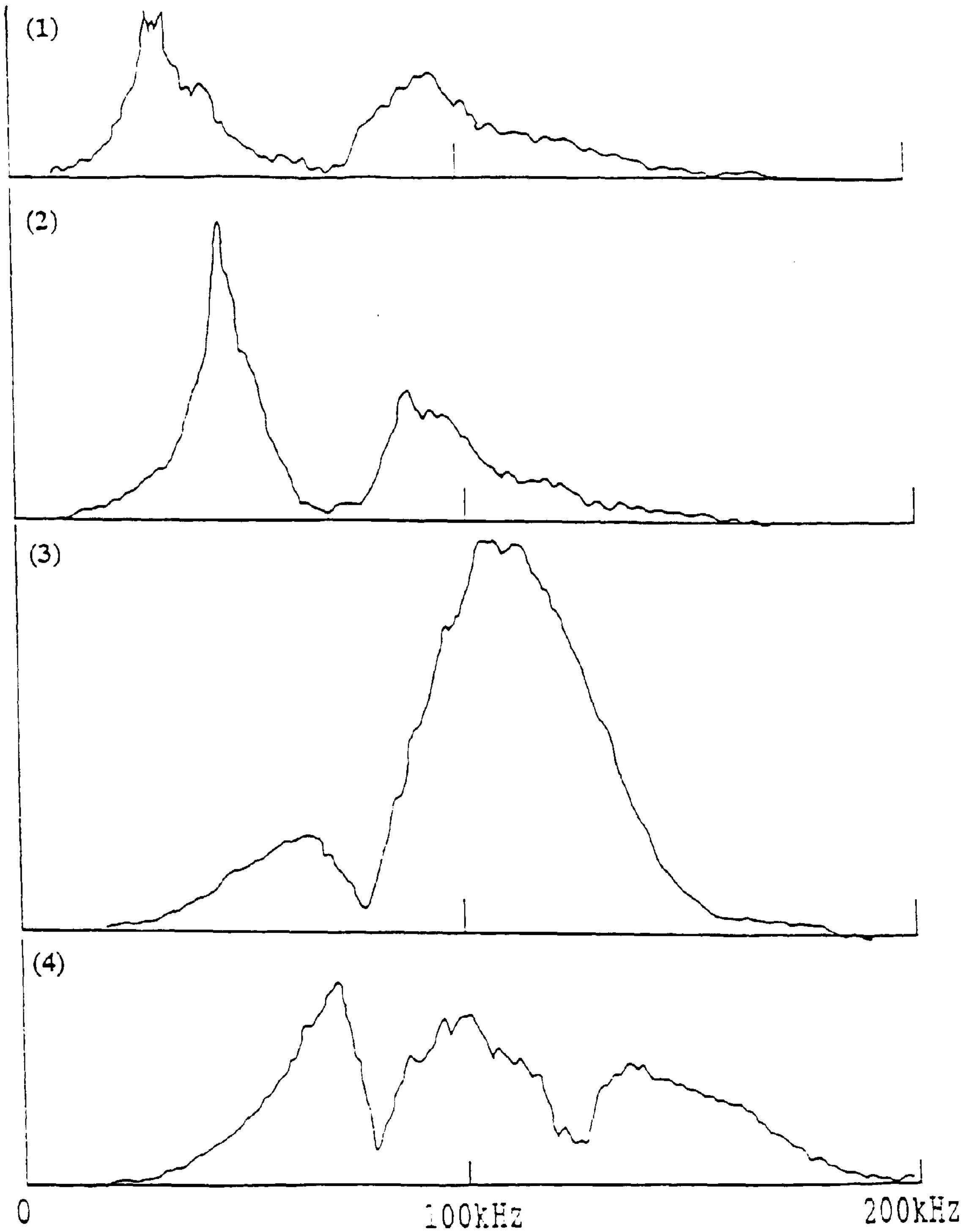


Figure 12

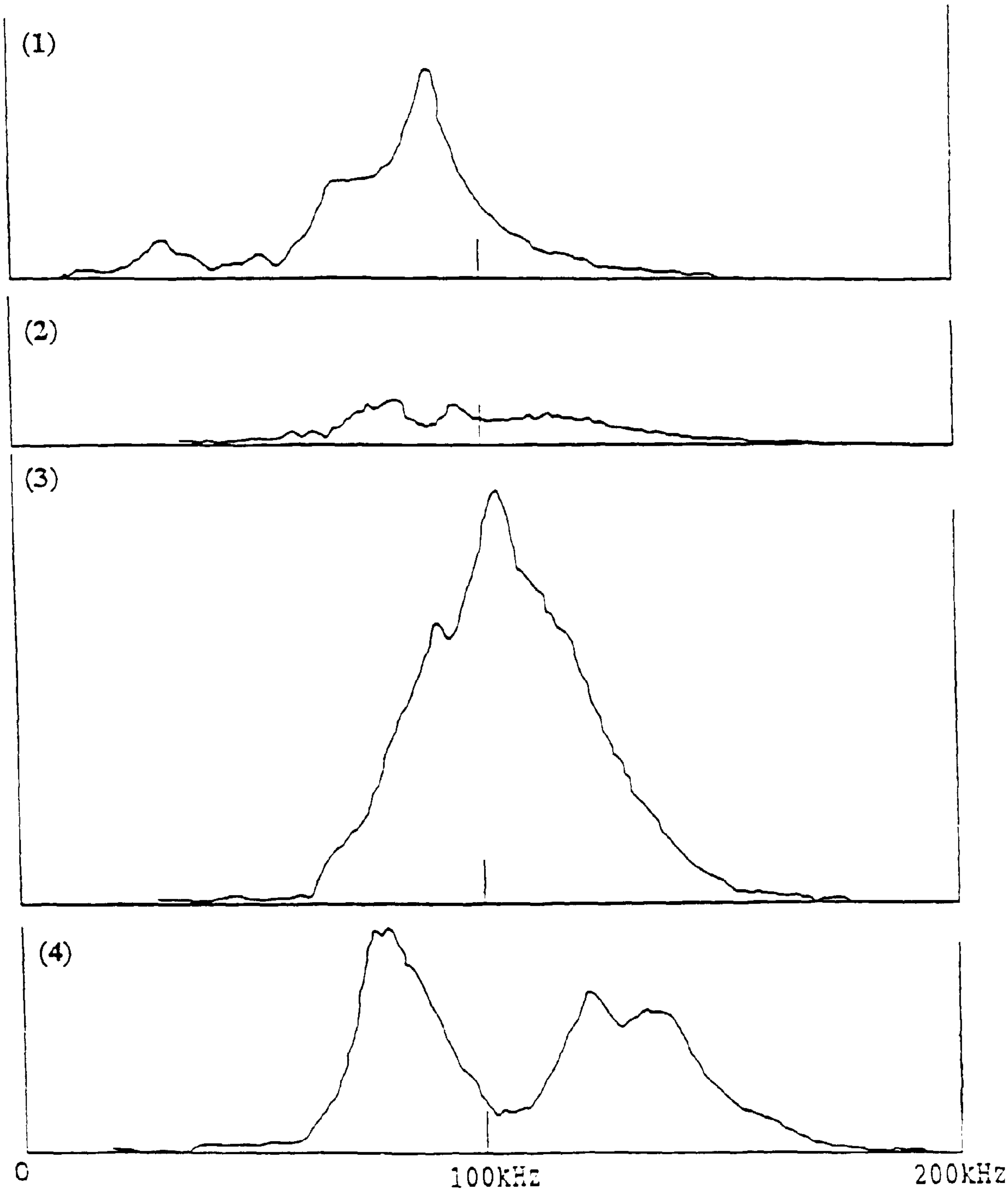
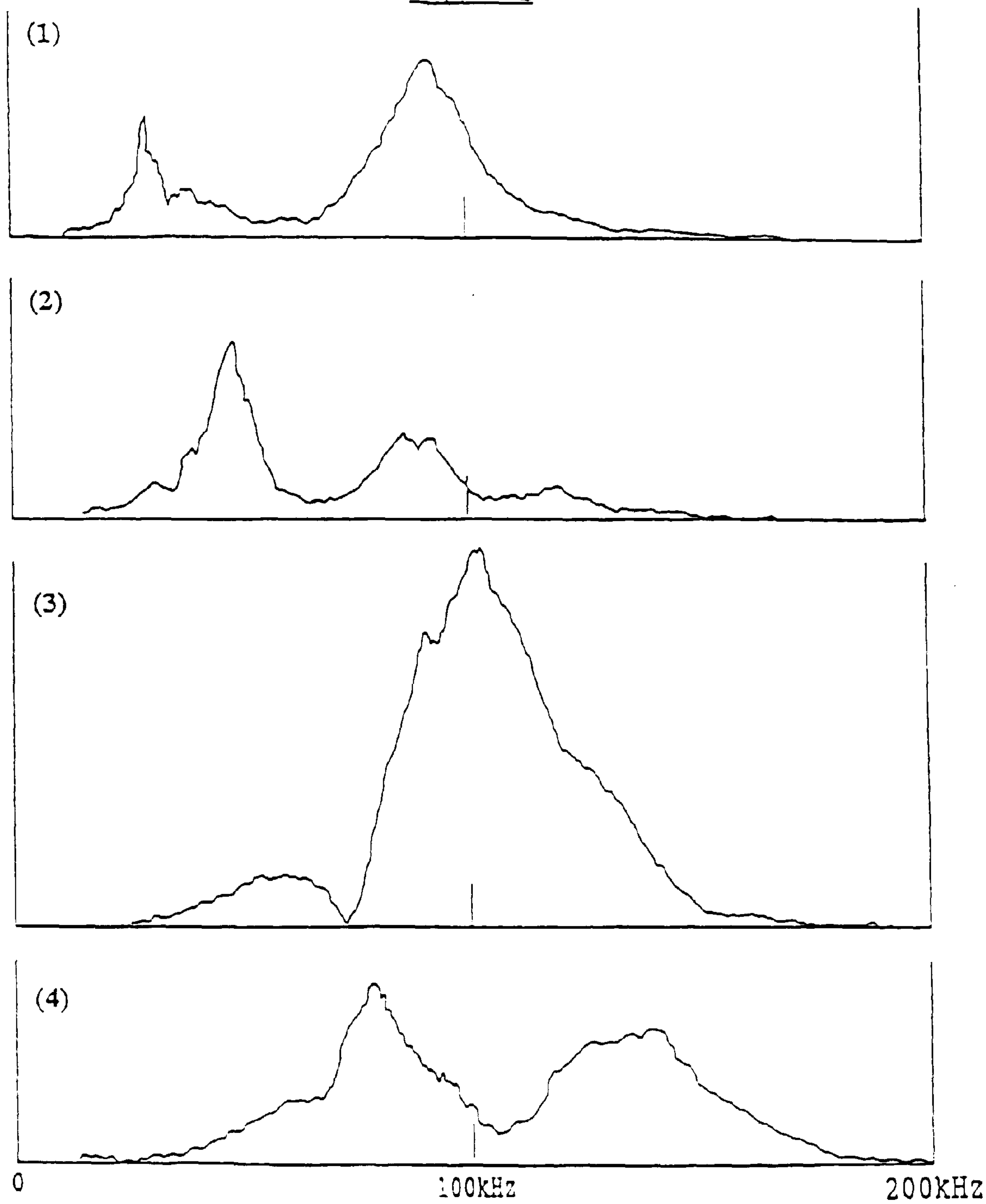


Figure 13



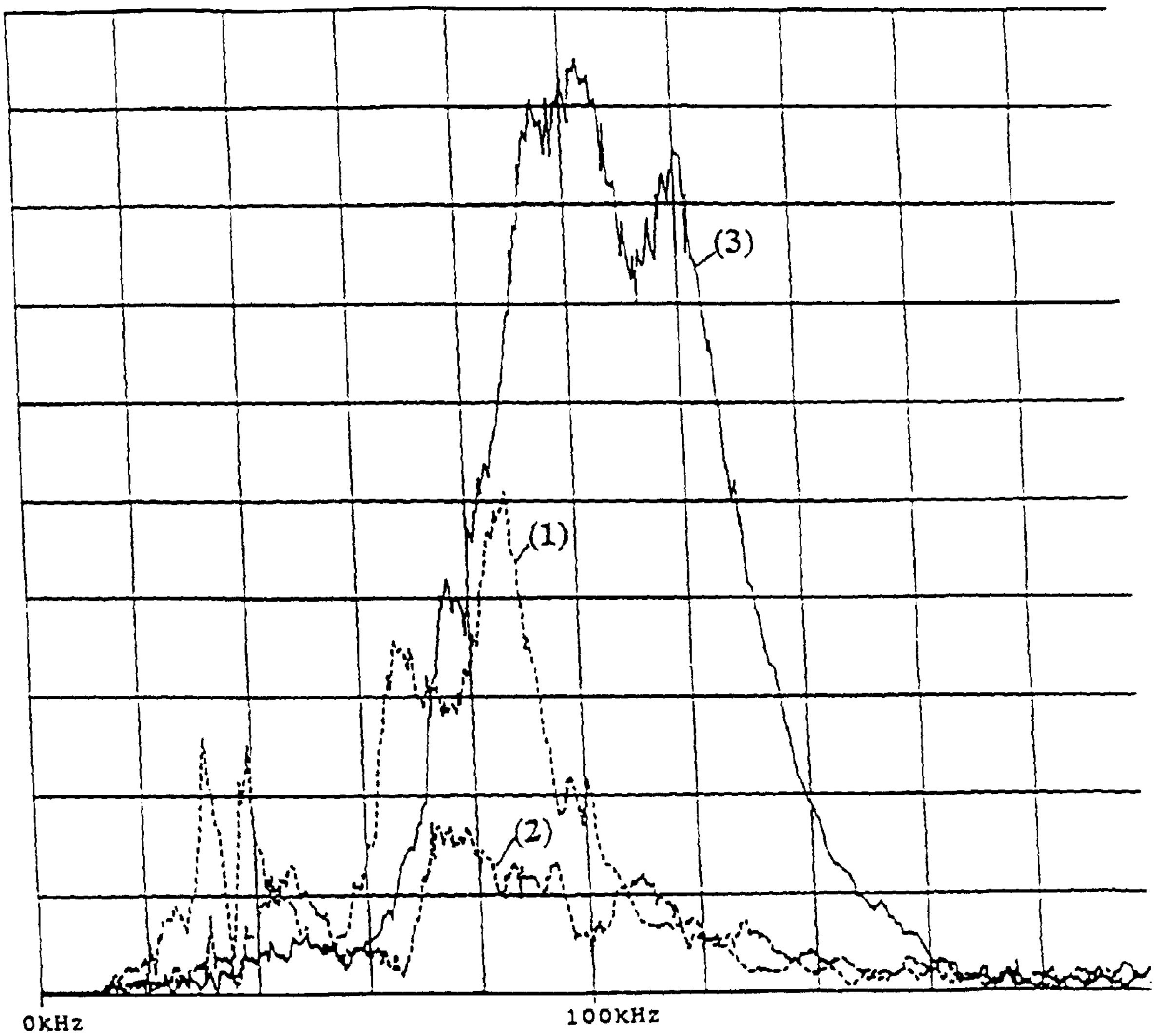


Figure 14