June 30, 1970 J. F. WOOD ET AL 3,518,460

ULTRASONIC TRANSDUCER EMPLOYING SUSPENDED PIEZOELECTRIC PLATE

Filed Oct. 30, 1968

FIG. 1

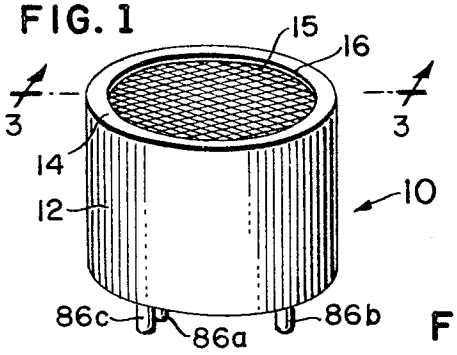


FIG. 2

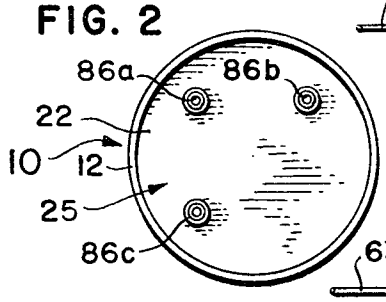


FIG. 3

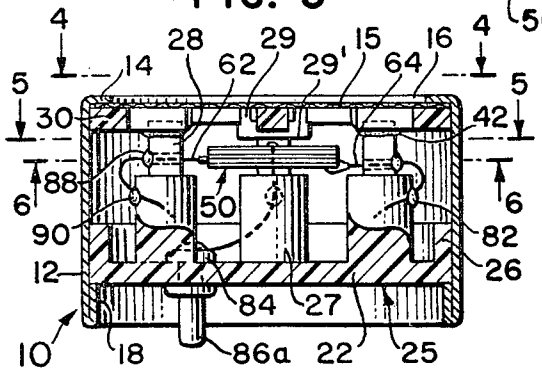


FIG. 4

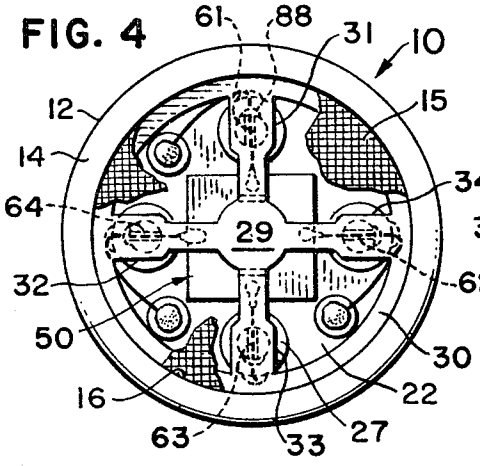


FIG. 5

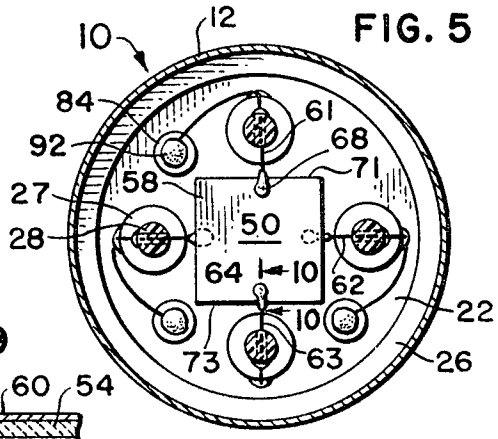


FIG. 9

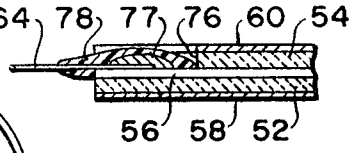


FIG. 10

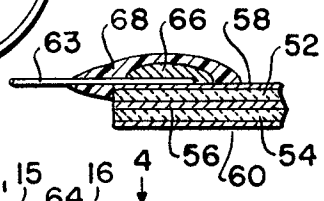


FIG. 6

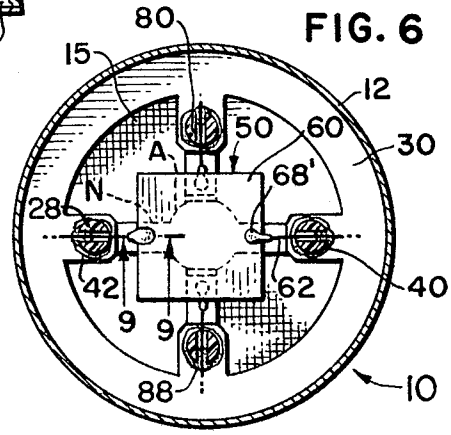


FIG. 7

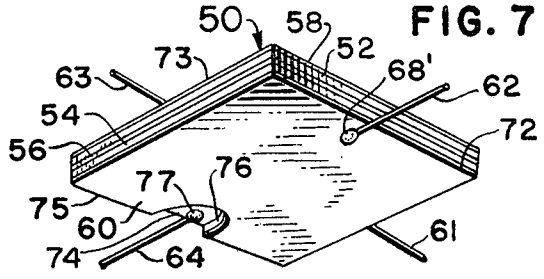
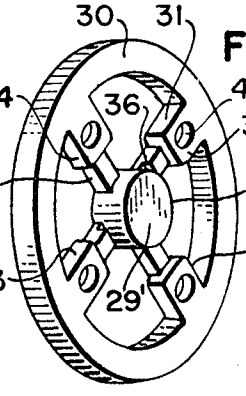


FIG. 8



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United States Patent Office 3,518,460
Patented June 30, 1970

3,518,460

ULTRASONIC TRANSDUCER EMPLOYING SUSPENDED PIEZOELECTRIC PLATE

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Filed Oct. 30, 1968, Ser. No. 771,751
Int. Cl. H01v 7/00
U.S. Cl. 310—8.2 6 Claims

ABSTRACT OF THE DISCLOSURE

An ultrasonic transducer has a laminated piezoelectric element supported by wires inside a cylindrical electrically insulative cage. The wires are connected to nodal points of the element by pressure-free solder joints covered with insulative cement. A phasing plug located at one end of the cage and a reflector plate located at the other end of the cage are joined by spaced posts. The cage and piezoelectric element are enclosed in a protective, electrically shielding casing.

Ultrasonic transducers for use in an air medium have heretofore been of magnetostrictive, electrostatic or piezoelectric types. Magnetostrictive transducers are relatively bulky, complex and expensive. Electrostatic transducers are simpler and less expensive but they have several disadvantages among which may be mentioned the following:

(1) Relatively high DC polarizing voltages are required.

(2) Reproducibility and uniformity of characteristics are poor due to variations in the insulating film used in their construction.

(3) Stability is poor due to changes in characteristics caused by humidity and aging.

(4) High driving voltages are required due to their high impedances.

(5) Waveform variations and distortion occur due to vibration, spurious resonances and non-linear electrostatic fields.

(6) Their frequency response curves are erratic and resonance frequencies drift.

Because of the above and other inherent disadvantages of magnetostrictive and electrostatic transducers, modern ultrasonic transducers largely employ piezoelectric elements. Such piezoelectric elements are made from ceramic materials such as lead zirconate and lead titanate. These elements are formed into single or laminated plates which can be arranged to vibrate in thickness, shear, or bending modes. Many practical applications of ultrasonic transducers operate in air just above the upper limit of audibility, in the range of approximately 20 kilohertz to 50 kilohertz. Higher frequencies can be used but greater absorption of ultrasonic energy occurs in air, and equipment cost is greatly increased. Many ultrasonic transducers are used in remote control and intrusion alarm applications. Here cost is an important factor and must be minimized. At the same time operating characteristics are rather stringent, requiring absolute purity of waveform and freedom from rattles, distortion and spurious resonances.

One typical, prior ultrasonic piezoelectric transducer is described in U.S. Pat. 3,109,111 issued to A. M. Wiggins on Oct. 29, 1963. In this transducer, the piezoelectric element is supported at vibratory nodes by metal tabs held in contact with the conductive surfaces of the element by spring pressure. Positioning of the element is determined by four notches formed in edges of the element.

When this prior transducer is employed as a transmitter (radiator) at continuous high power level, spurious resonances, rattles and undesired harmonics may be generated by the compliant metal supporting frames and contacting tabs. Positions of the tabs may shift in the notches to change resonant frequency. Wear occurs between the sharp, high stress contact area of the tabs and the soft, silver electrode coatings of the element, so that electrical contacts may become intermittent or open after a period of time. Changes in clamping pressure and position may occur due to aging or applied mechanical shock. Considerable bias force must be applied to the element by the frame and contact mounting tabs to obtain reliable clamping pressure. This introduces excessive prestress in the element which changes and adversely affects its operating characteristics.

The present invention is directed at overcoming the above and other difficulties in an ultrasonic piezoelectric transducer operable in air as a compressional wave transmitter (radiator) or receiver (microphone). According to the invention a square laminated piezoelectric plate is supported by suspension in space between a base plate and a phasing shadow or lens member. The base plate serves as a compressional wave reflector. The piezoelectric plate is supported without external, applied mounting or clamping pressure. The piezoelectric plate is suspended between insulating supports by wires secured to notched pins carried by the base plate. The wires are soldered to electrodes of the plates and covered with cement in such a way as to increase strength of the joint and peel resistance of the solder. The cement also contributes to damping of the wires to prevent generation of spurious resonances. Some of the wires terminate at external pins carried by the base plate. The phasing or shadow member is mounted over the piezoelectric plate. The piezoelectric plate is thus protectively mounted in an insulated "squirrel cage" which is in turn enclosed in a cylindrical, electrically shielding, metal basing.

The ultrasonic transducer and other advantages of its novel construction will be described in further detail in connection with the drawing, wherein:

FIG. 1 is a perspective view of an assembled encased ultrasonic transducer embodying the invention;

FIG. 2 is a bottom plan view of the transducer;

FIG. 3 is an enlarged vertical sectional view taken on line **3**—**3** of FIG. 1;

FIG. 4 is a top view, with portions of a protective screen broken away to show internal construction;

FIG. 5 and FIG. 6 are horizontal cross-sectional views taken on lines **5**—**5** and **6**—**6** respectively of FIG. 3;

FIG. 7 is an enlarged isometric view of the piezoelectric element, showing details of the underside thereof;

FIG. 8 is an oblique view of a phasing member employed in the transducer assembly;

FIG. 9 is an enlarged fragmentary sectional view taken on line **9**—**9** of FIG. 6; and

FIG. 10 is an enlarged fragmentary sectional view on line **10**—**10** in FIG. 5.

Referring to the drawing there is shown in FIGS. 1–6 an ultrasonic transducer **10** embodying the invention. The transducer is encased in a cylindrical casing **12** having an open front or top and covered by a circular protective screen **15** securely fitted at annular rim **14** of opening **16**. The screen freely passes compressional waves into or out of the casing depending on whether the transducer is employed as a compressional wave transmitter (wave generator or radiator) or as a compressional wave receiver (microphone). The open rear or bottom end of the casing may be turned inwardly to define a circumferential flange **18** which engages a circuit base plate **22** of an insulative frame or cage **27** to hold this frame or case in the casing.

The base plate **22** is cup-shaped with an annular flange **26** which frictionally engages the inner side of casing **12**. Integrally formed with the base plate are four cylindrical posts **27** spaced 90° apart. Upper ends of the posts are formed with integral cylindrical pegs **28** of reduced diameter. The cage **25** further includes a phasing disk or plug **29** supported by four radial arms **31–34** spaced 90° apart and integrally joined to an outer ring **30**; see FIG. 8. Ring **30** fits snugly inside the casing just under rim **14** of opening **16**, with the edge of screen **15** fitted between the ring **32** and rim **14**.

Arms **31–34** have inner sections **35** of reduced width and thickness, with notches **36** formed in two diametrally aligned arms **31, 33** adjacent to plug **29**. Outer portions **38** of the arms are thicker than the inner portions and are equal in thickness to that of the ring **30**. Blind holes or recesses **40** are formed in undersides of arms **31–34**. These holes receive upper free ends of pegs **28**. The pegs are secured by a suitable cement **42** so that the cage **25** constitutes a unitary rigid frame structure.

A square piezoelectric element **50** is disposed inside the cage **25**. Element **50** is a laminated structure including two thin ceramic wafers or plates **52, 54** bonded to opposite sides of a thin electrically conductive metal wafer or plate **56**. The outer exposed sides of the plates **52, 54** are coated with thin conductive films **58, 60** of silver or other suitable electrically conductive material. Films **58, 60** serve as electrodes for the laminated structure.

The element **50** is oriented so that its center is precisely aligned with the central axis of the cylindrical cage **25** and the casing **12**. The piezoelectric element normally vibrates in a bending mode. It has an active central area A outlined by arcuate dotted lines in FIG. 6. Plug **29** which is thicker than the arms **31–34** and ring **30** has an inner or bottom surface **29** precisely spaced from the adjacent central area of element **50** so as to magnify or maximize the compressional waves emitted by the vibratory element when used as a wave generator or radiator, and so as to obtain maximum drive of the piezoelectric element when ultrasonic compressional waves are applied thereto. Element **50** is precisely spaced from base plate **22** so that this plate serves as an efficient reflector to reflect back to the piezoelectric element compressional waves emitted thereby so as to reinforce mechanical vibrations of the element.

The critical positioning of the element **50** is maintained by four stiff wires **61–64**. Inner ends of wires **61** and **63** are disposed at centers of opposite marginal edges **71, 73** of upper film **58** and are secured by solder **66**. An insulative cement **68** such as epoxy is applied over the entire solder joint and extended slightly along the wire as clearly shown in FIGS. 5 and 10. This serves to reinforce the joint, prevent peeling off of the solder and to restrict vibration of the wire. The inner end of wire **62** is secured to the center of marginal edge **72** of bottom film **60** as shown in FIGS. 6 and 7 and is there secured by solder reinforced by cement **68'** in the same manner as illustrated in FIG. 10. The inner end of wire **64** is secured to the center of marginal edge **75** of center plate **56**. A notch **76** is formed in the adjacent marginal edges **75** of both film **60** and plate **54** so that the wire can be secured by solder **77** and insulative cement **78** as best shown in FIG. 9. Outer portions of the wires extend through holes **80** formed diametrally in peg **28**. The wires apply no tension to the element **50**. They simply support the element. The wires are frictionally engaged in holes **80**. From holes **80** the wires extend down to grooves or notches **82** formed in posts **27**. Lower ends of the wires **61–63** termniates at circumferentially spaced eyelets **84** located at upper or inner ends of three pins **86*a*, 86*b*, 86*c*** on plate **22**. The pins are secured in base plate **22** and extend axially downward therefrom for connection to an external electrical circuit. Cement **88** secures the wires to the pegs **28**.

Cement **90** secures the wires to posts **27**. Solder **92** secures the wires to the eyelets or terminals **84**.

The arms **31–34** supporting phasing plug **29** are located above nodal areas of vibration of the element **50** outside of area A as indicated by straight dotted lines N in FIG. 6. Similarly the cement covered solder joints and inner ends of the wires are located at nodal areas of the vibratory element **50**. The arms **31, 34** and the joints of the wires are located at outer ends of intersecting central axes of the element **50**.

By the arrangement described it will be apparent that the element **50** is suspended in space inside cage **25** and is supported by pressure-free connections to wires located at nodal areas of the vibratory element. The wires have sufficient stiffness to hold the vibratory element in precise position and have sufficient resiliency to offer a minimum of restraint to vibration of the element. The restraining effect is minimal and negligible since the points of connection are precisely located at nodal points or areas of the vibratory plate.

The provision of insulative cage **25** inside the casing **22** effectively insulates the conductive wires and pins from the metal housing and front screen. This prevents a shock hazard in AC operated equipment. The ring **30**, arms **31–34**, and plug **29** also protect the element **50** by serving as abutments for screen **15** to prevent it from being pushed into the casing.

If the transducer is to be used as a two-terminal assembly, external connections will be made to pins **86*a*, 86*b*** in circuits with electrodes **58, 60**, and there will be no external connection to pin **86*c***. If the transducer is to be used in an oscillator or filter circuit requiring taps to electrodes **58, 60** and center plate **22**, then external connections will be made to all three pins **86*a*, 86*b*, 86*c***.

In operation of the transducer as a transmitter alternating voltages of proper polarity and frequency will be applied to the electrodes and center plate, the element **50** will vibrate in a bending mode, bending alternately in opposite directions to emit compressional waves peaked sharply at a predetermined ultrasonic frequency. In operation of the transducer as a receiver or microphone, compressional waves at ultrasonic frequency will be applied to element **50** through screen **22**. The element **50** will respond by bending alternately in opposite directions to generate alternating voltages peaked at the frequency of the applied compressional waves.

The transducer described has particular utility in intrusion alarm systems. However it is of general utility and can be used in any system requiring an ultrasonic transducer of high Q.

Among the advantages of the construction described above are the following:

(1) The free and unrestrained suspension of the piezoelectric element without prestressing.

(2) Permanent electrical and physical connection of the supporting means to the piezoelectric elements.

(3) Elimination of abraded and intermittent contacts.

(4) Elimination of all supporting frames and mechanical parts in contact with the piezoelectric element to avoid spurious resonances or rattles.

(5) Simplicity of the mechanical and electrical assembly so that the assembly can be manufactured in large quantities at low cost.

(6) Enclosure of the piezoelectric assembly on all sides by an insulating cage inside an electrical shielding metal enclosure.

(7) Simple and reliable arrangement for connection to the center electrode such as required in certain oscillator and filter circuits.

(8) Use of plastic, energy absorbing insulating material to damp support wires, prevent spurious resonances, and increase joint strength.

(9) The transducer has a high Q, narrow bandwidth response.

(10) The piezoelectric element can be driven at relatively high energy level, limited only by the curie point temperature of the ceramic material, or the melting point of the solder in the joints of the wires to the electrodes.

What is claimed is:

1. An ultrasonic transducer comprising a flat piezoelectric member; thin, flat electrodes bonded to sides of the piezoelectric member; wires connected at one end thereof to said electrodes at edges of said member for supporting the same, points of connection at said wires being located at nodal points of vibration of said member so that a central portion of said member is free to vibrate; a rigid base plate; a plurality of spaced posts on one side of the base plate; means securing other ends of said wires with respect to said base plate so that the piezoelectric member is supported in space a predetermined fixed distance from said one side of the base plate to reflect compressional waves to the piezoelectric member for reinforcing vibrations of the piezoelectric member; a phasing disk; a ring mounted to said posts; and radial arms integral with said ring and disk holding said disk a predetermined other distance from said piezoelectric member adjacent said central portion thereof for maximizing and focusing compressional waves impinging on said piezoelectric member.

2. An ultrasonic transducer as defined by claim 1 wherein the piezoelectric member has a laminate structure comprising a pair of juxtaposed, flat, piezoelectric wafers, two of said electrodes being bonded to outer sides of the wafers, and a third one of said electrodes being disposed between and bonded to inner opposing sides of the wafers.

3. An ultrasonic transducer as defined by claim 2, wherein one of the piezoelectric wafers has a notch at one edge to expose a marginal portion of the third electrode thereat, one end of one of the wires being secured to said marginal portion of the third electrode.

4. An ultrasonic transducer as defined by claim 1 wherein said base plate, posts, ring, arms and disk are formed of insulative material and constitute a cage enclosing and mechanically protecting said piezoelectric member.

5. An ultrasonic transducer as defined by claim 4, further comprising an electrically shielding cylindrical housing enclosing said cage, said housing having open opposite ends; a screen at one end of the housing to pass compressional waves therethrough, said screen being disposed adjacent said ring; and circuit terminals mounted to said base plate at spaced points and exposed at the other open end of the housing for connection to an external circuit, certain of said wires being connected at other ends thereof to said circuit terminals.

6. An ultrasonic transducer as defined by claim 1 wherein said wires are connected to the electrodes by solder joints; and further comprising insulative plastic cement overlaying and bonded to end portions of the wires, the solder joints, and areas of the electrodes immediately surrounding the solder joints, so that the solder joints are reinforced and so that vibration of the wires is effectively prevented while the piezoelectric member vibrates.

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U.S. Cl. X.R.

179—100.1; 310—8.6, 9.4; 340—15