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Brown et al.

[11] **3,876,890**

[45] **Apr. 8, 1975**

[54] **LOW REFLECTED ENERGY TRANSMISSION STRUCTURE TRANSDUCER HEAD**

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[21] Appl. No.: **463,529**

[52] **U.S. Cl.** .... **310/8.2;** 73/194 A; 310/8.7; 310/9.4; 259/1 R; 340/8; 340/10

[51] **Int. Cl.** **H01v 7/00**

[58] **Field of Search** .... 310/8.2, 8.3, 8.7, 9.1, 310/9.4; 340/8, 10; 259/1 R, DIG. 17, DIG. 44; 73/194 A, 67.5 R, 67.6, 67.7, DIG. 4; 181/.5, 142

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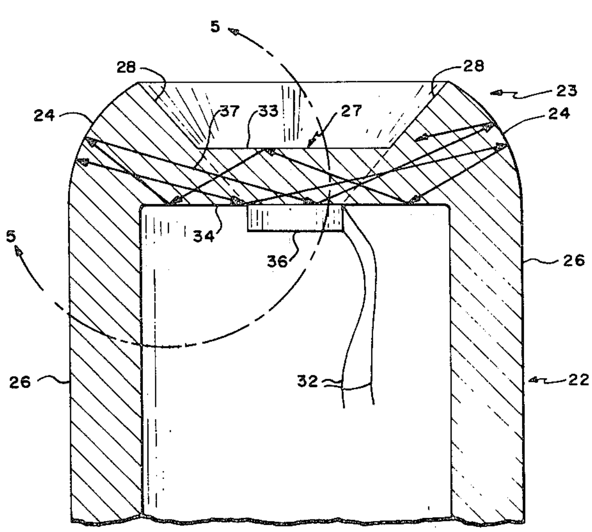
Attorney, Agent, or Firm—Flehr, Hohbach, Test, Albritton & Herbert

[57] **ABSTRACT**

Reflected ultrasonic wave energy within a transducer head produced by a crystal transducer mounted therein is trapped within the head by the geometric configuration of the head until the reflected wave is substantially dissipated. The geometric configuration includes a diaphragm upon which the transducer is mounted and a frusto-conical surface extending outwardly from one face of the diaphragm and intersected by a surface of revolution for forming a solid of revolution therebetween. The angle of conicity is selected to align the frusto-conical surface with the principle acoustic dispersion or shear angle in the transducer head material. The head may be mounted in a flow conduit with the frusto-conical surface in communication with the fluid and the transducer mounted on the opposite side of the diaphragm, or it may be mounted with the frusto-conical surface exterior to the conduit, and the transducer mounted on the diaphragm surface adjacent thereto. The surface of revolution may take any one of the number of forms as long as it has a geometric shape, such as to reflect within the head substantially all energy waves which emanate outwardly from the edge of the mounted transducer.

16 Claims, 9 Drawing Figures



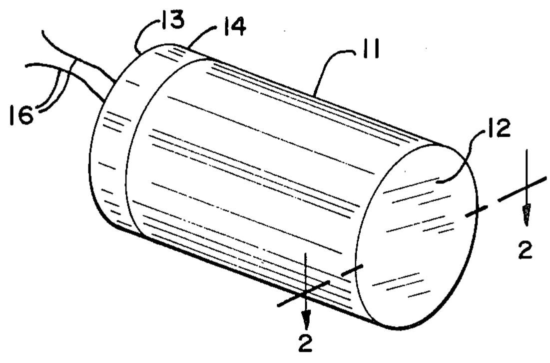


FIG.—1

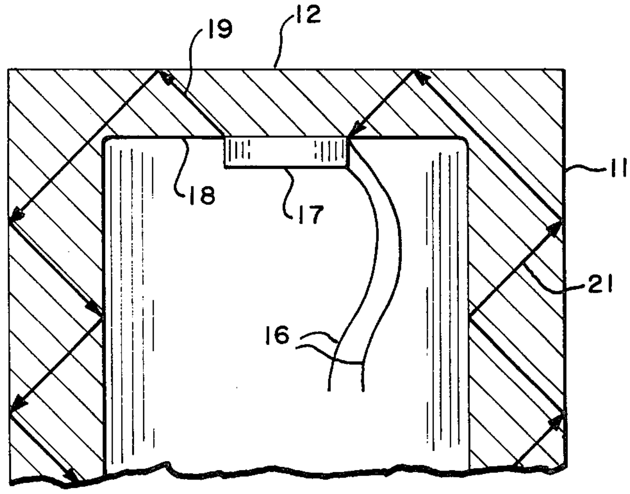


FIG.—2

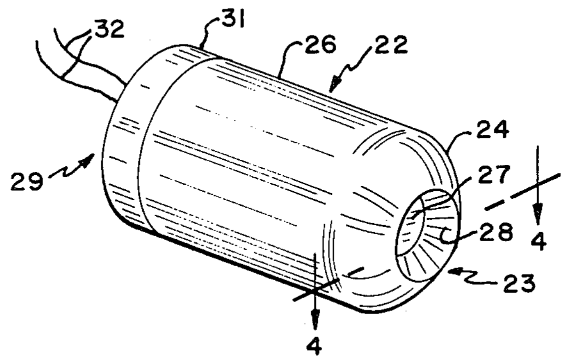


FIG.—3

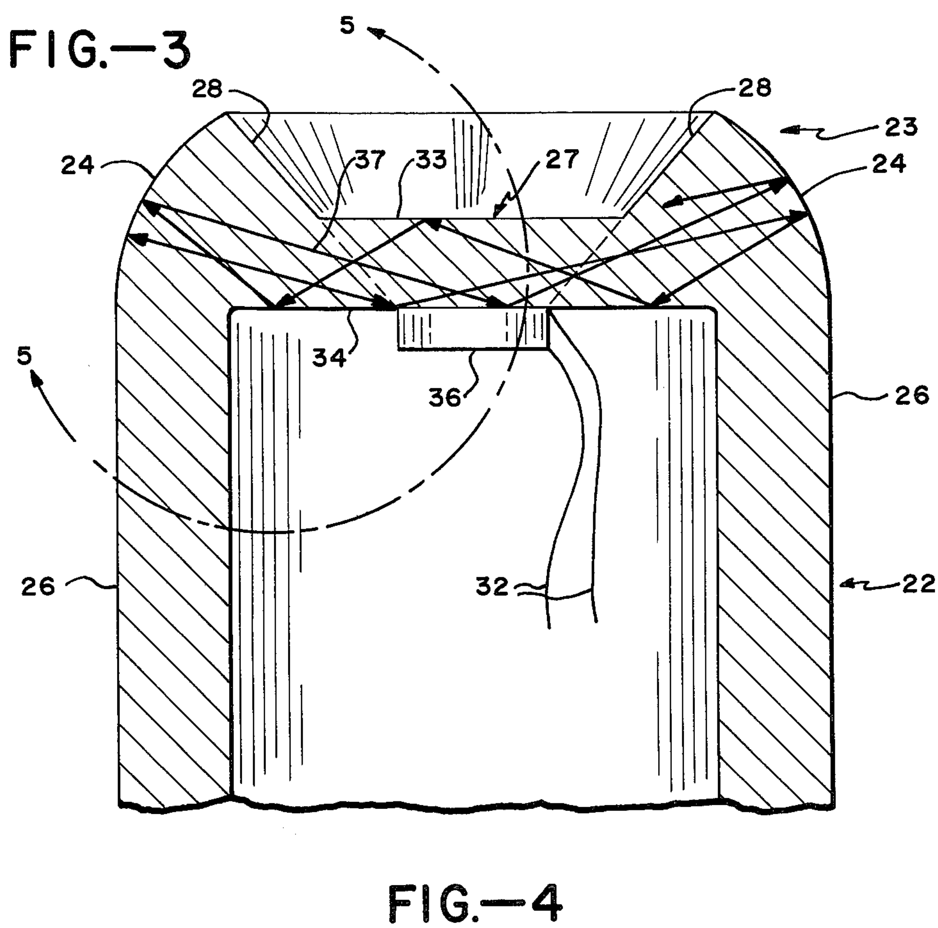


FIG.—4

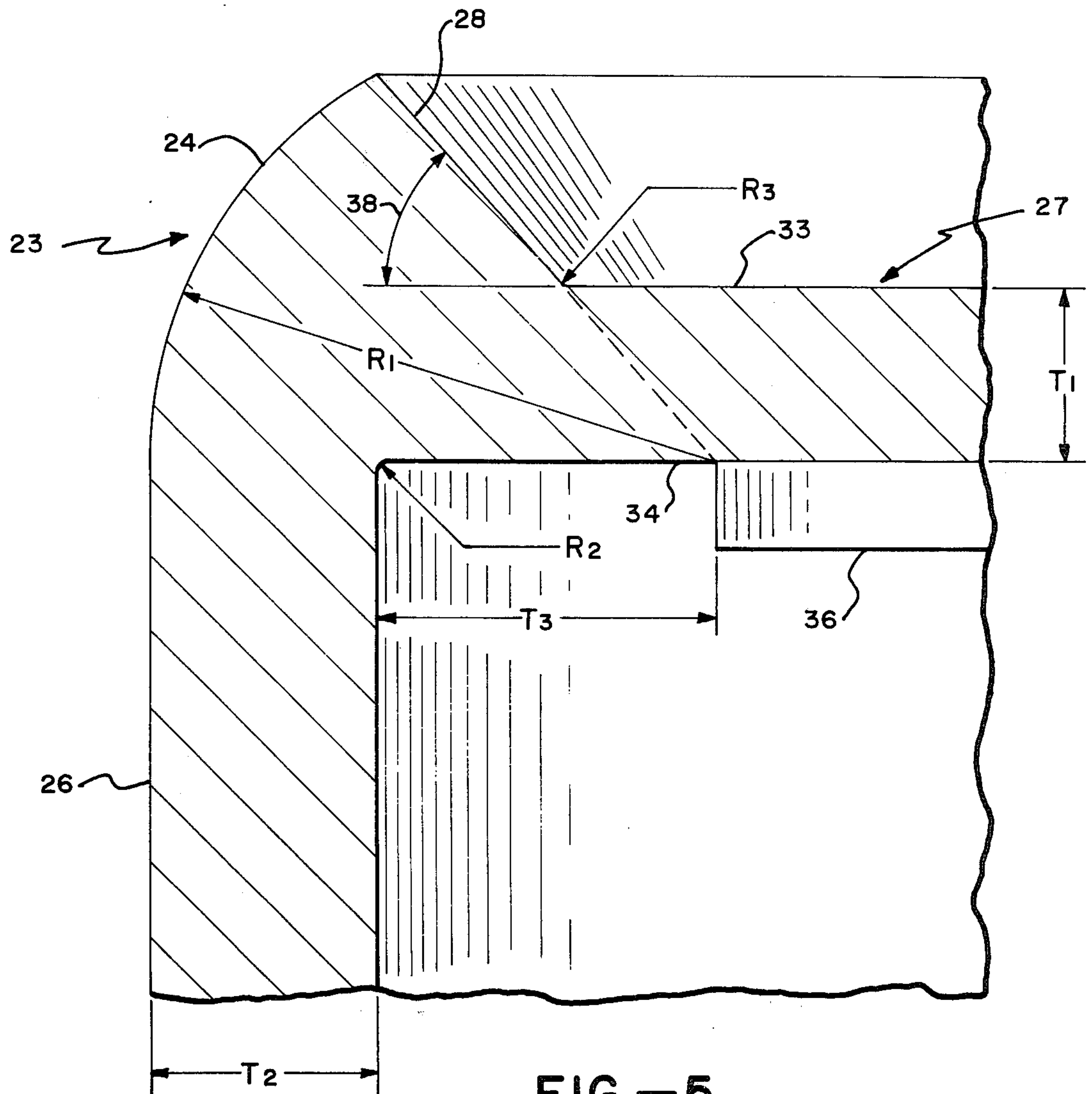


FIG.—5

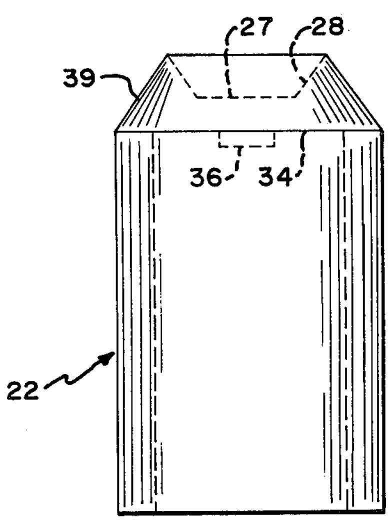


FIG.—6

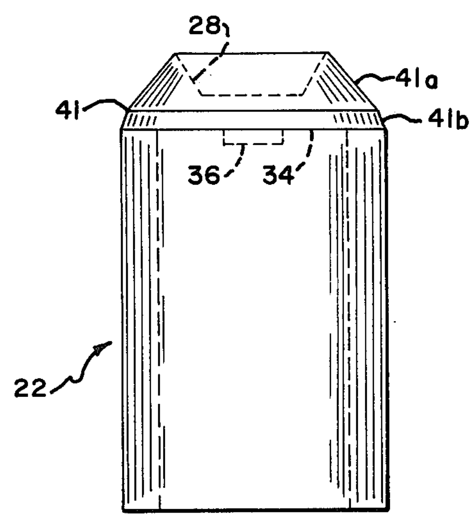


FIG.—7

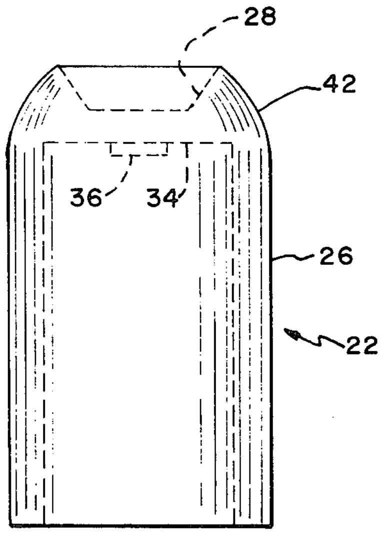


FIG.—8

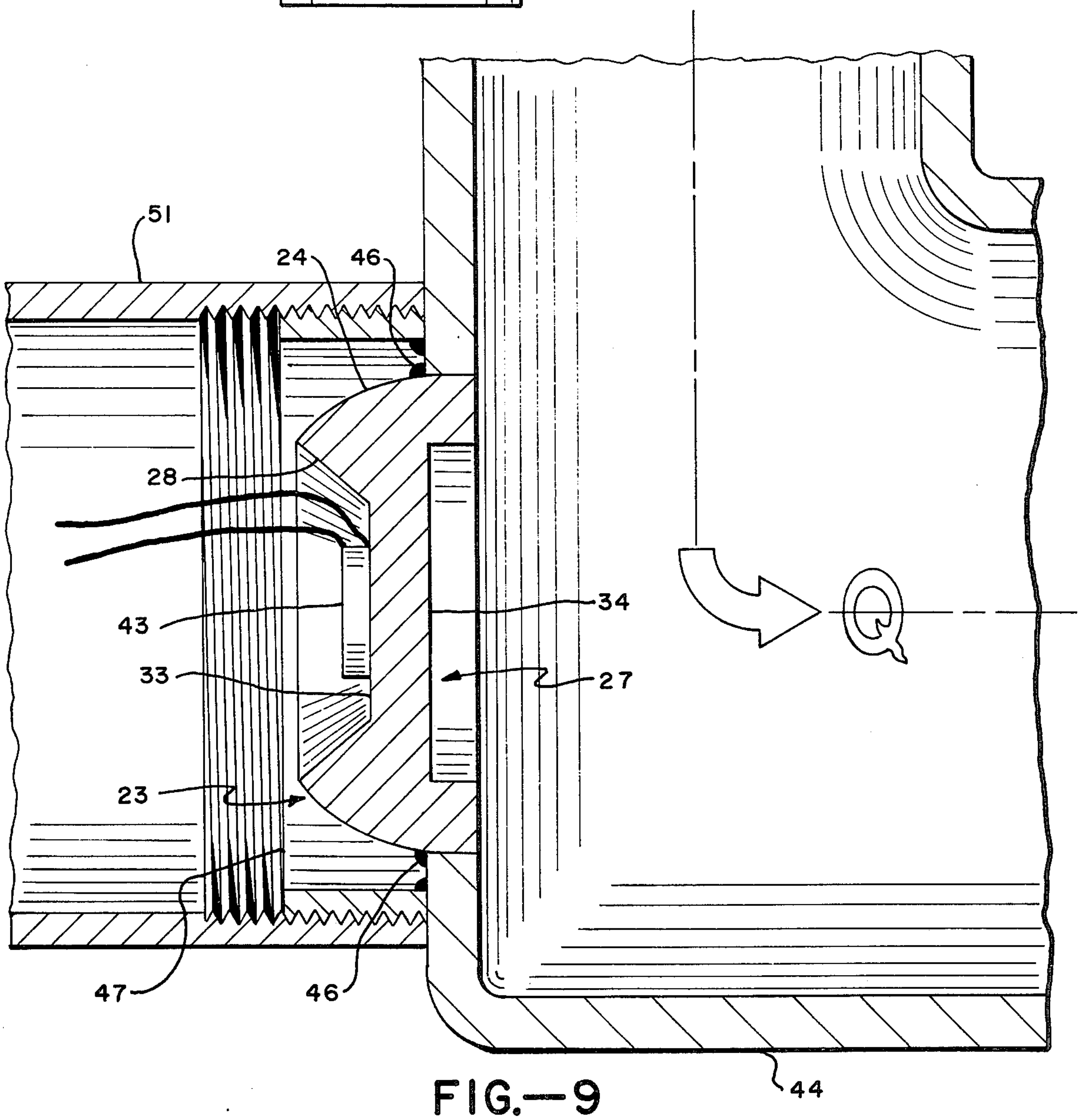


FIG.—9

LOW REFLECTED ENERGY TRANSMISSION STRUCTURE TRANSDUCER HEAD

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a transducer mounting head which reflects a neligible amount of ultrasonic wave energy through the head and adjacent mechanical parts, and more particularly to a transducer head for use in fluid measurements of high pressure fluids in which transducer head sections are substantial to withstand the high pressures.

2. Description of the Prior Art

A crystal transducer mounted in a transducer head generates ultrasonic wave energy through vibrations in the crystal which are excited by an electrical signal for the purpose of transmitting the ultrasonic energy through a protective diaphragm for ultimate transmission through the fluid. The crystal transducer itself must be protected from the pressures and the chemical affects of the fluid by means of a transducer head. In many applications the transducer head is a metal or some other dense material which readily transmits ultrasonic energy waves at higher velocity than any fluid being measured due to the relatively high density of the transducer head material compared to the fluid being measured. Ultrasonic energy when it impinges the surface of the transducer head creates an acoustic discontinuity between the surface of the transducer head and the surface of the liquid at the point of impingement. Some portion of the wave energy at the point of impingement will be transmitted into the fluid and another portion will be reflected back into the structure of the transducer head. When a transmitter and a receiver transducer head are mounted in a metal pipe it is readily seen that a substantial level of ultrasonic energy is transmitted through the mechanical structure to effectively "short circuit" the ultrasonic energy transmitted through the less dense fluid in the flow conduit. Resulting interference at the receiver transducer has caused great uncertainty in ultrasonic flow meter indications in the past.

There is, therefore, a need for a head for mounting a transducer used in either the transmitter or receiver mode which retains reflected energy within the head mounting the transmitting transducer and which blocks receipt of energy into the head mounting the receiving transducer.

SUMMARY OF THE INVENTION AND OBJECTS

The head for mounting a transducer for transmitting and receiving ultrasonic energy through an interface with a fluid being measured includes a diaphragm upon which the transducer is mounted between the transducer and the fluid. Extending from one face of the diaphragm face which is aligned with the principle acoustic dispersion angle of the material from which the head is fabricated. The frusto-conical walls extending away from the diaphragm together with the one face of the diaphragm form a cavity and also intersect with an outer surface of revolution which extends to the plane of the surface of the diaphram opposite the one face. The solid of revolution bounded by the outer surface of revolution, the frusto-conical walls and the two faces of the diaphragm is formed so that when the transducer is mounted on one face of the diaphragm, substantially all energy waves emanating outwardly from the edge of the transducer at angles with the diaphragm surface which are more acute than the principle shear angle in the transducer material, are reflected back to the point of origin or toward the surface forming the frusto-conical cavity. The reflected wave continues to be reflected within the head by the geometric surface configuration of the head until the energy of the reflected wave is substantially dissipated by reflections within the head and by partial transfer of energy to the surrounding fluid.

In general it is an object of the present invention to provide a head for mounting a transducer which contains reflected energy waves.

It is another object of the present invention to design a head for mounting a transducer in which only the pressure requirements on the transducer need be considered in determining the wall thickness of the head.

It is another object of the present invention to provide a head for mounting a transducer in which material is selected solely on the bases of structural strength and compatibility of the material with the fluid being measured.

It is another object of the present invention to provide a head for mounting a transducer which blocks substantially all reflected ultrasonic energy waves from conduction into a fluid conduit structure and which blocks substantially all conduction of ultrasonic energy waves from the conduit structure to the head.

Additional objects and features of the invention will appear from the following description in which the preferred embodiment has been set forth in detail in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an isometric view of a transducer head which is old in the art.

FIG. 2 is a sectional view along the line 2—2 of FIG. 1.

FIG. 3 is an isometric view of the low reflected energy structure head.

FIG. 4 is a sectional view along the line 4—4 of FIG. 3.

FIG. 5 is a partial sectional view of the head of FIG. 4.

FIG. 6 is a side elevational view of a low reflected energy structure head having a frusto-conical outer surface of revolution.

FIG. 7 is a side elevational view of a low reflected energy head having a double frusto-conical outer surface of revolution.

FIG. 8 is a side elevational view of a low reflected energy head having a paraboloid outer surface of revolution.

FIG. 9 is a sectional view of a low reflected energy head with the transducer mounted on the side of the diaphragm adjacent to the frusto-conical diverging walls.

DESCRIPTION OF THE PREFERRED EMBODIMENT

One of the principal problems in designing transducer mounting heads for use in fluid flow measuring systems lies in the transmission of ultrasonic wave energies generated by the transducers through the head structure and the pipe or conduit structure from the transmitting transducer to the receiving transducer at the other end of the flow measurement path. Typical mechanical configurations for the measurement of the fluid flow may be seen in U.S. Pat. No. 3,780,577, copending patent application Ser. No. 250,760 filed May 5, 1972, and copending patent application Ser. No. 278,987 filed Aug. 9, 1972. As seen therein fluid conduit and transducer mounting head structure provides a continuous mechanical path between the ultrasonic transducers mounted in the head. Since this structure is generally of a more dense material, such as metal, than the fluid flowing through the conduit, an ultrasonic energy wave short circuit may exist through the mechanical structure between the transducers. Since the receiving transducer operates on the reversible principle of providing an electrical output for a mechanical input, the short circuit energy waves generate a spurious receiver output. The ability to measure the fluid flow in the conduit by utilizing the receiver output resulting from receipt of energy waves transmitted through the fluid is thus reduced.

The problem described above is magnified in those applications where the fluid being measured is flowing under high pressure. Mechanical considerations require that the mounting head for a transducer have thick cross sections to provide the additional structural strength required to withstand the high pressures. This increased mass in the transducer mounting head presents a problem to the head designer which requires design compromises as may be seen by referring to the existing standard transducer mounting head design of FIG. 1. As seen therein the head 11 is cylindrical in shape having a blunt end supporting a diaphragm 12, through which ultrasonic energy is transmitted to the fluid. Typically the mounting head 11 is sealably inserted through an opening in a wall of a flow conduit and an access end 13 external to the conduit is sealed by a cover 14 through which extends a hermetically sealed set of electrical conductors 16.

Referring to FIG. 2, a cross section of the standard head shown in FIG. 1 is seen. A transducer 17 of the piezoelectric type is centrally mounted on the inside face 18 of diaphragm 12.

The basic behavior of ultrasonic energy waves propagated through a transducer mounting head includes transmission of the principal amount of energy through the diaphragm 12 in a direction normal to the exterior face of the diaphragm and into the medium in communication with the diaphragm. As the edge of the transducer 17 is approached the ultrasonic energy waves tent to propagate along paths dispersed from the normal to the diaphragm face 33. The material of the transducer mounting head 11 has a shear angle which in the case of steel is known to be approximately 45°. The energy propagated along the shear line from the edge of transducer 17 is known to be approximately 3db down, or to represent the half power down locus as compared to the energy transmitted directly normal to the face of transducer 17. An acoustic dispersion angle exists as a property of materials which conduct acoustic energy walls. The acoustic dispersion angle defines a line relative to the face of the material into which acoustic energy waves have been transmitted, along which acoustic energy waves of one half power are transmitted, compared to energy waves transmitted in a direction normal to the material face. The shear angle and acoustic dispersion angle are therefore approximately the same in most materials and will hereinafter be used interchangeably. Energy waves propagated at angles less than the acoustic dispersion angle in a particular material, in steel less than 45° from inside face 18 for example, decrease in power approaching zero as the angle approaches zero.

Referring to FIG. 2 it may be seen that an ultrasonic energy wave 19 emanating from the edge of transducer 17 spreads outwardly within diaphragm 12 striking the outer face of diaphragm 12 at an angle of incidence and being reflected at a reduced energy and at an equal angle of reflection to subsequently impinge on the outside surface of the wall of head 11 and traveling down the wall to enter the flow conduit structure. Energy transmission within the head 11 is by a combination of shear waves and compressional waves and the head 11 may even resonate the energy passed through the head structure. As is also shown in FIG. 2 a received ultrasonic energy wave 21 may in like manner travel up the wall of head 11, reflecting off of the outer surface of diaphragm 12 to impinge on the front face of transducer 17.

The primary factors upon which the design of a transducer head diaphragm is based include prevention of fluid pressure from the fluid flow from entering the transducer head to be lost outside of the flow conduit, protection of the ultrasonic energy transducer from fluid chemical and pressure effects, and provision of a mechanical impedance match between the characteristic mechanical impedance of the crystal transducer and the characteristic mechanical impedance of the fluid in the conduit. The structural considerations are easily determined for withstanding fluid pressures for a diaphragm of a given material by reference to standard texts for determination of structural capabilities of circular flat plates, such as Machinery's Handbook, page 436, published by Industrial Press Inc. Mechanical impedance matching where the characteristic impedance of the crystal is generally high and the characteristic impedance of the flowing fluid is generally much lower, is ideally determined by the relationship $Z_D=(Z_C Z_F)^{1/2}$; where Z_D is the mechanical impedance of the diaphragm, Z_C is the mechanical impedance of the transducer crystal, and Z_F is the mechanical impedance of the fluid in the flow conduit.

In like manner the thickness of the side walls of a transducer mounting head may be calculated by reference to standard text materials, such as the Machinery's Handbook mentioned above at page 441. When reflected wave energy through the structure of the transducer mounting head must be considered, the diaphragm and the wall thickness requirements become interdependent to minimize such energy transmission. It is desirable to arrive at a transducer mounting head design in which the wall thickness and diaphragm thickness may be calculated independently, governed solely by the pressure requirements within the flow measuring system and wherein the materials selection need only be governed by the compatability requirements of the materials with the fluid in the conduit.

A transducer mounting head 22 for accomplishing the above independence of wall and diaphragm design is shown at 22 in FIG. 3. Transducer mounting head 22 has a diaphragm end 23 with an outer surface of revolution 24 blending into the outside diameter of walls 26. Diaphragm 27 may be seen at the bottom of a cavity on the diaphragm end 23 formed by frusto-conical diverging walls 28 extending from an intersection with diaphragm 27 and intersecting outer surface of revolution

24. An access end 29 on mounting head 22 has a cover 31 sealably attached thereto through which sealed connectors provide an electrical conducting path for a pair of conductors 32.

Referring to FIG. 4 a sectional view of the forward or diaphragm end of mounting head 22 is shown. In this embodiment diaphragm 27 is shown having a thickness extending between a front face 33 and a rear face 34. The thickness of diaphragm 27 is determined independently of the thickness of the walls 26 by reference to the three primary considerations cited above. A transducer 36 is centrally mounted on the rear face 34 of diaphragm 27. In this embodiment the material from which mounting head 33 is fabricated is steel and the primary shear angle is approximately 45° as discussed above. Transducer 36 mounted on rear face 34 has a predetermined diameter depending upon the characteristics of the ultrasonic energy wave which must be propagated through the fluid in the conduit. The factors included in the determination of the diameter and other dimensions of the piezo-electric crystal transducer 36 include the scattering properties present in the fluid to be measured. For example, gasoline or water have minimal scattering properties, while a slurry of suspended particles may carry a high density of scattering bodies. The mean diameter of the scattering particles in the fluid should be small compared to an energy wave length produced by the transducer. Therefore, the ultrasonic frequency produced by the transducer will be lower for slurries, thereby producing longer wave lengths, and higher for clear fluids which have few or microscopic particles only.

As is well known to those skilled in the art, a proper crystal diameter to thickness ratio must be kept to guarantee crystal oscillation in the desired mode, specifically in a thickness mode parallel to the cylindrical axis of the transducer disc in this embodiment. The location of frusto-conical walls 28 relative to diaphragm 27 is determined by inclining walls 28 to be aligned with the acoustic dispersion or shear angle of the head material and imagining an extension of walls 28 through the thickness of diaphragm 12 to intersect rear face 34 at the diameter of crystal 36. Since the thickness of diaphragm 27 is predetermined by the considerations mentioned above, the diameter of front face 33 at the intersection with frusto-conical walls 28 is thereby determined. Outer surface of revolution 24 is shown to have a constant radius of curvature R1 as shown in FIG. 5 with a center rear face 34 at the edge of transducer 36 where it is adjacent to rear face 34.

An ultrasonic energy wave 37 is shown in FIG. 4 from the left edge of transducer 36 and passing through the material of head 22. The course of the energy wave 37 is shown by the arrows as it strikes surface 24 at an angle normal to a tangent at the point of incidence and is reflected from surface 24 back along its outward path indicated at 37. Reflection from the surfaces of head 22 continue as indicated by the arrows showing subsequent reflection from the opposite side of surface of revolution 24, rear face 34, front face 33, rear face 34, and so on, maintaining the reflections of energy wave 37 within the transducer mounting head 22 until it is substantially dissipated. Comparison with FIG. 2 shows that the mounting head embodying the inventive concept of FIG. 4 retains reflected energy therein, preventing it from traveling down the walls 26 unlike the energy wave transmission which occurs in the standard head of FIG. 2.

Turning now to FIG. 5, some details in the construction of the low reflected energy structure transducer head will now be discussed. As mentioned above, the thickness of the diaphragm 27 is determined primarily by considerations of structural capability to withstand fluid pressure, protective provisions for the transducer crystal, and impedance matching between the transducer and the fluid being measured.

The thickness T2 of the walls 26 is determined considering only the structural requirements to withstand the pressure within the fluid being measured. The shear angle for the material from which mounting head 22 is fashioned is represented at 38 and is shown as approximately 45°. The diameter of rear face 34, and therefore the inside diameter of the walls 26, is determined as follows. Face 34 must have a diameter which will accommodate central mounting of transducer 36 and which will reflect ultrasonic energy waves which spread from the edge of transducer 36 at angles relative to face 34 which are greater than the shear angle 38, and are therefore reflected from front face 33. Such energy waves will then be reflected in turn by rear face 34 and directed to impinge upon outer surface of revolution 24, if the distance T3 from the outer edge of transducer 36 to the inside diameter of wall 26 is twice the thickness T1 of the diaphragm. The diameter of rear face 34 is therefore the sum of the diameter of transducer 36 and four times the thickness T1 of the diaphragm 27. R1 in the embodiment of FIG. 5 is a radius with its center at the intersection of the edge of transducer 36 and rear surface 34. Radii R2 and R3 are provided as small as possible to prevent erratic reflection of energy waves in the head and large enough to prevent structural stress risers from occuring within the head material.

FIGS. 6, 7 and 8 represent alternate configurations of the mounting head 22 which are similar in construction to the head shown in FIGS. 3, 4 and 5 except for the outer surface of revolution on diaphragm end 23. FIG. 6 shows an outer surface of revolution 39 which is frusto-conical having its base in the same plane as rear face 34 and intersecting frusto-conical walls 28. The angle between the base and the surface 39 is such as to reflect the higher energy spreading waves toward the diaphragm end of head 22. FIG. 7 has an outer surface revolution 41 described by an upper and a lower frusto-conical surface 41A and 41B respectively. The base of frustum 41B is in the plane of rear face 34 and frustum 41A intersects frusto-conical walls 28. As in FIG. 6, surface 41 is designed to reflect spreading energy waves toward the diaphragm end 23. FIG. 8 has an outer surface of revolution 42 which is a paraboloid blending with the outside diameter of walls 26 at an extension of the plane of rear face 34 and intersecting frusto-conical walls 28. The embodiment of FIG. 8 is also designed to reflect spreading energy waves within the diaphragm end 23 of mounting head 22. In all of the embodiments shown in FIGS. 3–8 frusto-conical surface 28 and front face 33 are in communication with the fluid to be measured.

Another embodiment of the inventive concept disclosed herein is shown in FIG. 9. A transducer 43 of the piezo-electric type as described above is mounted on front face 33 of diaphragm 27. FIG. 9 shows the mounting head having the same configuration as the diaphragm end of mounting head 22 in FIG. 4. Since transducer 43 is mounted on front face 33 in this embodiment the head is sealably placed within the wall of the flow conduit 44 by means of weldments as shown in 46 with rear face 34 in communication with the fluid flowing therethrough. A supporting collar 47 is secured to the outside of flow conduit 44 surrounding the diaphragm end 23 of the mounting head and carries external threads 48 for mating with internal threads 49 formed on a protective cover 51 for shielding transducer 43 from the environment. The concept disclosed herein is operative for a transducer mounted on front face 33 with rear face 34 in communication with the fluid as well as with the transducer on rear face 34 and front face 33 in communication with the fluid.

A transducer mounting head has been disclosed which provides for minimal reflection of ultrasonic energy waves through the structure of the head and subsequently through the flow conduit structure to the opposite or receiving head. Reflected energy noise is thus greatly reduced at the receiver by trapping reflected energy within the transmitting head and blocking reflected energy from entering the receiving head. Energy waves approaching along an incoming path toward the transducer mounting head 22 are blocked from the surface of the diaphragm 27 on which transducer 36 is mounted by the same geometry that prevents exit of such energy waves. A wave travelling up wall 26 in FIG. 3, for example, will strike either surface 28 or 24, be reflected back down wall 26 or onto surface 24 or 28 respectively, and then back down wall 26. Noise producing mechanical resonance within structural parts has been eliminated and materials of various types may be used for fabrication of the mounting heads by utilizing known acoustic dispersion angles for the head material and orienting the frusto-conical walls adjacent to the front face of the diaphragm to substantially align with the acoustic dispersion angle. Any one of several outer surfaces of revolution may be used at the diaphragm end of the mounting head, depending upon available tooling and other factors which provide for ease of fabrication.

We claim:

1. In a head for mounting a transducer for energy exchange with a fluid, a diaphragm for mounting the transducer having first and second faces, frusto-conical diverging walls extending from said first face away from said second face at an angle supplementary to the acoustic dispersion angle of the head material, an outer surface intersecting said frusto-conical walls and forming a solid of revolution therewith extending to the plane of said second face, said solid of revolution reflecting substantially all energy waves which emanate outwardly from the edge of the transducer at angles with the mounting surface more acute than the principle shear angle in a direction which is on the side of a normal to the point of wave incidence which is towards said first face, whereby reflected wave energy is retained within the head until substantially dissipated.

2. In a head as in claim 1 wherein the transducer is a piezo-electric crystal having a diameter substantially equivalent to the diameter described by the intersection of an imaginary extension of said frusto-conical diverging walls and said second face, and wherein said second face has a diameter equivalent to the sum of the diameter of the transducer and four times the thickness of said diaphragm.

3. In a head as in claim 2 wherein the transducer is centrally mounted on said second face, together with cylindrical side walls depending from said outer surface having an inner diameter defined by the diameter of said second face, whereby when the head is sealed in the wall of a fluid conduit with said first face in communication with the fluid, the transducer may receive energy from and impart energy to the fluid.

4. In a head as in claim 2 wherein the head material is steel and the acoustic dispersion angle is approximately 45°.

5. In a head as in claim 2 wherein the transducer is mounted on said first face and the head is sealably mounted in a wall of a fluid conduit with said second face in communication with the fluid, together with a cover mounted on the exterior of the fluid conduit for providing protection for the head and the transducer.

6. In a head as in claim 1 wherein said outer surface is a frustum of a cone.

7. In a head as in claim 1 wherein said outer surface describes an upper and a lower frustum of a cone, and wherein the base of said upper frustum has the same diameter as the upper surface of said lower frustum.

8. In a head as in claim 1 wherein said outer surface is a paraboloid of revolution.

9. In a head as in claim 1 wherein said outer surface has a constant radius of curvature in cross section, said radius extending normal to the locus of points describing an intersection of an extension of said frusto-conical diverging walls and said second face.

10. A head fabricated of a material having a principal shear angle substantially coinciding with an acoustic dispersion angle for mounting a transducer for transmitting ultrasonic energy through a fluid medium and for receiving ultrasonic energy transmitted through a fluid medium comprising a solid of revolution bounded by a first planar diaphragm surface, a second planar diaphragm surface parallel to said first surface, an internal frusto-conical surface intersecting said first diaphragm surface and diverging therefrom extending away from said second diaphragm surface, and an external surface intersecting said frusto-conical surface and extending to the plane of said second diaphragm surface, whereby when said transducer is mounted on said diaphragm the geometry of said solid of revolution reflects substantially all energy waves emanating outwardly from the edge of the transducer in such a direction as to retain them within said solid of revolution until substantially dissipated.

11. A head for mounting a transducer as in claim 10 wherein the transducer has a predetermined diameter and a predetermined thickness between said first and second planar diaphragm surfaces, and wherein said internal frusto-conical surface forms an angle with the axis of the cone which provides substantial alignment with the principle shear angle in the head material, and wherein an extension of said internal frusto-conical surface which intersects said second planar diaphragm surface describes a circle thereon equivalent to the diameter of the transducer, thereby defining the diameter of said first planar diaphragm surface.

12. A head for mounting a transducer as in claim 11 wherein said external surface has a constant radius of curvature in cross section, said radius extending from the mounted edge of the transducer.

13. A head for mounting a transducer as in claim 12 wherein said head material is steel having a principal

shear angle which is approximately 45°, and wherein the diameter of said second planar diaphragm surface is equivalent to the sum of the diameter of the transducer and four times said predetermined diaphragm thickness.

14. A head for mounting a transducer as in claim **10** together with depending cylindrical walls having an outside surface meeting said external surface and having a thickness sufficient to withstand pressures in the fluid when the head is sealably inserted in the wall of a fluid conduit with said first planar diaphragm surface in communication with the fluid and the transducer mounted centrally on said second planar diaphragm surface.

15. A head for mounting a transducer as in claim **10** wherein the head is sealably mounted in the wall of a conduit containing the fluid having said second planar diaphragm surface in communication with the fluid and wherein the transducer is centrally mounted on said first planar diaphragm surface, together with a housing surrounding the head for protecting the transducer.

16. A head for mounting a transducer as in claim **10** wherein said solid of revolution intercepts substantially all ultrasonic energy waves approaching along an incoming path at said internal frusto-conical and said external surfaces, so that they are reflected outwardly in reverse direction on the incoming path and are prevented from impinging on said first and second planar diaphragm surfaces.

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