

[54] SONAR TRANSDUCER ASSEMBLY

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340/8, 9, 10, 12, 14

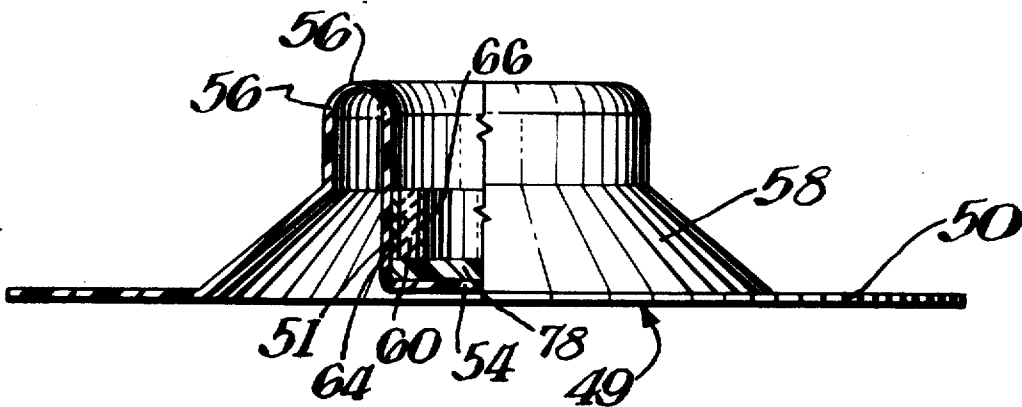
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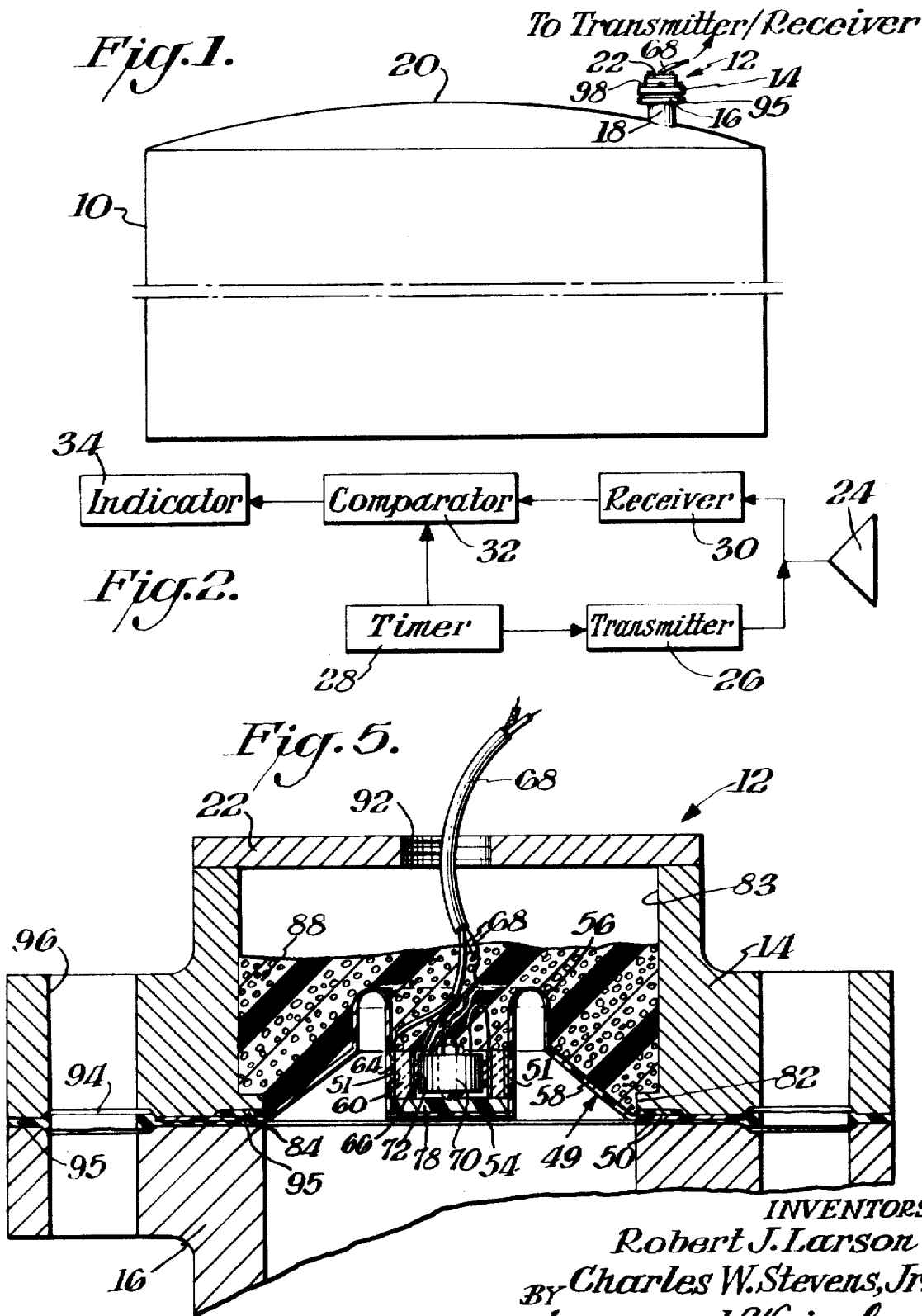
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[57]                      **ABSTRACT**  
The sonar transducer assembly described includes a seamless diaphragm having a hollow cylindrical cavity closed at one end, an axis perpendicular to the plane of the diaphragm, an annular 45° reflector, and an annular decoupling ring between the cavity and the reflector. A cylindrical sound transducer is positioned within the cavity such that when it is energized, the sound waves are generated radially outward through the cavity wall until reflected by the reflector along the axis of the diaphragm. This diaphragm may be positioned within a flange mounted in the nozzle or exhaust pipes of bulk storage bins or tanks. The seamless diaphragm insulates the transducer from any corrosive effects of the material stored therein and at the same time permits the sound waves to travel down to the storage enclosure for determination of the level of the material stored therein.

14 Claims, 6 Drawing Figures





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*Fig. 4.*

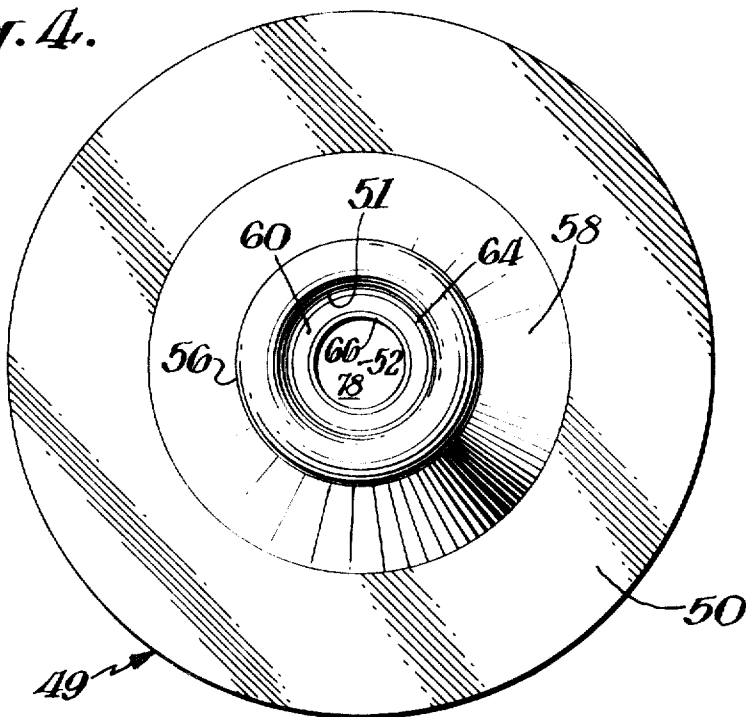


*Fig. 3.*

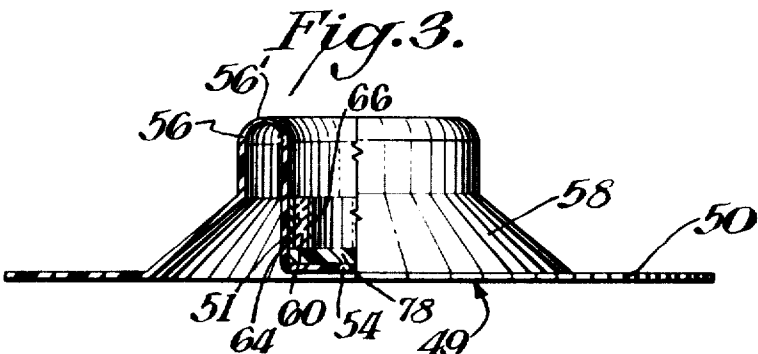
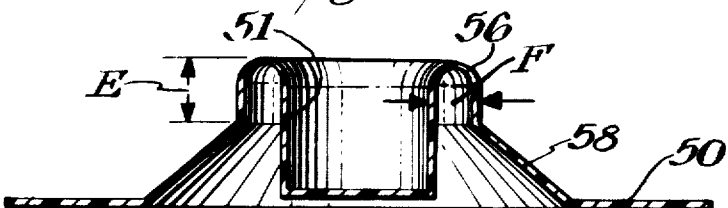


*Fig. 6.*



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## SONAR TRANSDUCER ASSEMBLY

### BACKGROUND OF THE INVENTION

This invention relates to a sonar transducer assembly and, more particularly, to a diaphragm mounting assembly for a sound transducer that is not only efficient but physically isolates the transducer from the region into which the sound waves are directed.

There are many, many applications within industry where it is necessary to determine the content or level of materials, both liquid and solid, that are stored within a storage tank or enclosure. Various sundry mechanisms and devices have been employed for this purpose. Among these devices are the so-called contact sensors which employ floats and the like to determine fluid level. These are sometimes satisfactory, but more often not, particularly in those cases wherein the storage fluid is either gummy or has a high viscosity which tends to inhibit the operation of the float. An additional problem encountered with these so-called contact sensors is that if the stored materials are of a corrosive nature they will tend to react with the float mechanisms and other sensor mechanisms and impair their proper operation. Another problem arises if the contact sensor is mounted on a device in which there is a seam or threaded connection exposed to the corrosive action of the stored materials. The resulting corrosion of the seam or threaded connection renders it difficult, if not impossible, to remove the sensor without a great deal of difficulty sometimes requiring that the sensor be cut out with a torch.

Capacitance sensors have often been used to overcome many of the inherent disadvantages of the contact types of level sensors. On the other hand many of the stored fluids tend to convert to highly viscous or solid materials over a period of time which changes the dielectric constant and hence impairs the efficient and accurate operation of the capacitance probe. Furthermore, many of the stored materials do not have a sufficiently high dielectric constant to permit sensing by capacitive techniques.

In an effort to overcome many of these problems, sonar type devices have been utilized of late to sense the level of the stored material. These sonar devices are often mounted in the nozzle or vent pipe at the top of the storage enclosure and operate to direct a sonar beam down into the enclosure. By measuring the time required for the sound waves to travel down to the surface of the fluid or material and be reflected back, an indication as to the level of the material stored in the tank is obtained. Unfortunately, even with these sonar transducers in many cases, the mounting mechanism is openly exposed to the corrosive nature of the stored fluids which, as noted hereinbefore, creates many problems particularly when it is desired to remove and/or change the transducer element. Furthermore, most of the devices now in use, and even those wherein the transducer itself is isolated from the corrosive action of the fluid by a diaphragm-like device, employ flat crystals. Unfortunately, in order for flat crystals to resonate at the desired frequencies, the required thickness renders them relatively inefficient. Such inefficiency requires excessive power levels in order to generate the sound impulses. While high power levels are not always a disadvantage, in those cases wherein flammable materials are stored, such high energy levels can be inherently dangerous and clearly cannot pass many of the

standards imposed by most testing laboratories such as Underwriter Laboratories. Another problem encountered with large crystals is that with the high mass they do not make an efficient receiver. Hence, in many cases two crystals are required, one for transmitting and one for receiving. This in itself provides an additional disadvantage in requiring an excessive amount of space, which often is not available, and tedious crystal matching.

Accordingly, it is an object of this invention to provide an improved sound transducer assembly which overcomes many of the disadvantages of those available in the prior art.

Another object of this invention is to provide an improved sound transducer assembly which is particularly suitable for use in determining material storage levels.

Still another object of this invention is to provide an improved sound transducer assembly which is self-contained, efficient and isolated from the region under test.

### BRIEF DESCRIPTION OF THE INVENTION

According to an embodiment of this invention, a sonar transducer assembly includes a seamless plastic diaphragm defining a central, hollow cylindrical portion having an axis and closed at one end with the other end curved outwardly back on itself to form an annular ring-like decoupling section, an outer flange, and an annular reflector section joining said decoupling section and said outer flange. The assembly also includes a cylindrical transducer positioned coaxially in the cylindrical portion of the diaphragm and means to energize the transducer. This has the advantages of producing sonic energy to be reflected by the reflector section in a direction parallel to the axis and permits the cylindrical transducer to be isolated from the region being exposed to the sound energy. This diaphragm-type design facilitates (1) placement of the transducer in the nozzle or vent pipe of storage tanks utilizing conventional flanges and (2) potting the diaphragm within a mounting flange to prevent the transducer from being easily damaged and improve its overall efficiency.

In the preferred embodiment of this invention, the cylindrical transducer is of electrostrictive material which radiates sound waves radially outwardly from the axis of the transducer. This permits the usage of a relatively lightweight transducer with reduced ring time and more efficient reception of the reflected returning waves. The curved portion of the decoupling section is formed to have a thickness less than that of the adjoining diaphragm sections thereby to decrease sound conductivity between the reflector and the transducer. Furthermore, the ratio of axial length of the decoupling section to the annulus of the decoupling section is less than 5 to 1 to maintain adequate support for the transducer.

In a particular application, this diaphragm is mounted within the central bore of a flange and the bore is then filled with a low density cellular material to render the reflector more rigid and to protect the transducer itself from physical damage.

### BRIEF DESCRIPTION OF THE DRAWINGS

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention, itself, however, both as to its organization and methods, as well as additional

objects and advantages thereof, will best be understood from the following description when read in connection with the accompanying drawings, in which:

FIG. 1 is an elevation view of a typical storage enclosure having a nozzle on top in which there is mounted within a flanged section, a sonar transducer assembly constructed in accordance with this invention;

FIG. 2 is a block diagram of a typical sonar transmitting and receiving circuit for measuring distances that may be used with this invention;

FIG. 3 is a side elevational view, partly cutaway, of the diaphragm portion of the transducer assembly constructed in accordance with this invention;

FIG. 4 is a plan view of the diaphragm illustrated in FIG. 3 particularly showing the ring-like decoupling section with the transducer mounted therein;

FIG. 5 is a cross-sectional view of the entire transducer assembly particularly showing the diaphragm mounted within a flanged member as illustrated in FIG. 1 and showing the detail of the mounting assembly and the positioning of the transducer therein; and

FIG. 6 is a cross-sectional view of an alternative embodiment of the transducer diaphragm illustrating a modification of the decoupling section.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

There appears in FIG. 1 a typical storage tank or bin 10 in which either bulk materials or liquids are stored. The storage may be either long term or for immediate usage. The material stored for example could be cement, sand, oil, various acids, or other chemicals corrosive and non-corrosive that would find utilization in various industrial processes. Whatever the material stored therein, there is provided in accordance with this invention a transducer assembly 12 which is mounted within a flanged member 14 affixed to a mating flange 16 positioned on the nozzle or vent pipe 18 in the roof or cover 20 of the tank 10. Wires 68 extending from the cover 22 of the transducer assembly 12 are passed to a transmitter-receiver of conventional design which is shown by way of illustration in the block diagram of FIG. 2.

There is seen in this block diagram a reflector 24 in which there is mounted a transducing element (not shown) which is energized by electrical signals from a transmitter 26 controlled to periodically pass such signals to the transducing element by a timer 28. The signals are directed toward the interface between the gas and the liquid or the gas and the solid stored in the tank 10. These signals are reflected at the interface back upwardly (in the drawing) to the transducer assembly 12 (FIG. 1) or the reflector 24 of FIG. 2 and thereby passed on to the receiver 30 for processing and amplification. A comparator 32 compares the time required for the signals to be transmitted downwardly from the transducer assembly 12 through the tank 10 and be reflected by the gas-liquid/solid interface and back to the transducer assembly 12. This time difference between transmission and return of the reflected signal is an indication of the quantity of material held in the storage tank 10. This time period is indicated by the indicator unit 34 which may be a gauge, meter or other suitable type of read out device responsive to the comparator.

The details of the transducer assembly 12 and in particular the reflector therefor are shown more clearly in FIGS. 3, 4 and 5. The configuration of the reflector is

seen most clearly in FIGS. 3 and 4. In these figures the reflector is seen to include in effect a diaphragm 49 which includes an outer flange 50 as well as a central hollow cylindrical portion 51, having an axis 52 (FIG. 4), which is closed at the lower end 54. The other end of the cylindrical portion 51 is curved outwardly and folded back on itself to form an annular ring-like decoupling section 56 that is U-shaped in cross-section as seen in FIG. 3. The decoupling section and the outer flange are joined by an annular reflector section 58 which lies at a 45° angle with respect to the axis 52, i.e., the reflector section 58 is frusto-conical in shape. A cylindrical or ring-like transducer 60 is coaxially positioned in the cylindrical portion 51. The height of the transducer should not exceed the height of the reflector section 58.

The entire diaphragm 49 is formed integrally to have no seams and preferably is formed of a plastic material. Any suitable plastic may be used such as polyethylene, polyvinyl chloride, polytetrafluoroethylene sold commercially as "TEFLON," or any of the other suitable plastics that are rigid and are generally impervious to chemical action and reaction. The curved portion 56' of the decoupling section 56 is seen to be formed to have a relatively thin thickness dimension. This is to provide sonic decoupling between the reflector section 58. In some embodiments it is also desirable to form at least the inner portion cylindrical section 51 to have a relatively thin thickness dimension, i.e., less than the thickness of the flange 50 and reflector section 58. Desirably the thickness of this decoupling radius 56' should be less than 30 percent of the thickness of the reflector portion of the diaphragm 49. The requirement here is that the decoupling radius 56' be sufficiently thin as to have compliance to effectively sonically decouple the reflector 58 from the transducer 60 so that sonic energy appearing in either place is substantially insulated from that appearing at the other. The cylindrical section 51 is thin to enhance the transmission of sound energy therethrough.

To complete the construction of the transducer assembly 12, as is seen in FIG. 5, the transducer element 60 may be formed of any substance which exhibits the electrostrictive effect or for that matter any structure capable of generating sonic impulses radially. It is known that all crystals have a second order electrostrictive effect in which a distortion occurs in the crystal that is proportional to the square of the electric displacement of the crystal. This distortion is quite small except in ferro electric materials such as Rochelle salt, barium titanate, lead zirconate titanate, etc. and apparently is due to stresses induced by changing the alignment of the ferro electric domains upon electrification. This distortion normally occurs in the direction of the electric field. In this instance an electric field is applied across the annulus of the ring-like crystal 60 by plated electrodes 64 and 66 to which lead wires 68 are connected as by soldering or other suitable means. Actually, these lead wires 68 are coupled to the electrodes 64 and 66 through an impedance matching transformer 70, which is positioned centrally within the crystal 60 and separated therefrom by a damping ring 72. This damping ring 72 has the effect of reducing ring time of the crystal 60 after it has received an energizing pulse.

The crystal itself is inserted into the cylindrical portion 51 and potted, using a suitable potting compound, in position to the inner wall of the cylindrical portion

51. The crystal should have a height no greater than the rise of the reflector section — otherwise the radiating sound energy would not be reflected. A hollow, cylindrical shaped damping ring 72 is positioned coaxially within the transducer 60 and also potted. The damping ring 72 may be foam rubber or any other material suitable for damping and reducing ringing of the transducer after each energizing pulse. One such material that has been successfully used is a product sold by B.F. Goodrich known as SC-41 Celcote. Preferably, an epoxy compound should be used for potting the crystal and damper which is very slow setting up. An epoxy having a two-day or more setting up time is desired such that air bubbles appearing between the outer crystal walls and the cylindrical portion 51 of the diaphragm all are allowed to rise and escape. Air bubbles are undesirable since they would cause refraction of the radiated sound wave. The crystal should fit closely to the inner wall of the portion 51. Furthermore, the potting compound should not be rigid but should permit some movement to enable adequate coupling of the crystal to the diaphragm. A suitable potting compound, for example, is available from Tra-Con, Inc. of Medford, Massachusetts and requires 72 hours in order to cast. Any other suitable known epoxies may also be used.

The entire crystal and damper 72 may be seated upon a disk 78 which may be of butyl rubber, 50 to 60 durometer, or other suitable cushioning material which would insulate the axial lobe vibration of the crystal from the diaphragm thereby to inhibit extraneous, unwanted radiation downwardly into the tank. Thus assembled the diaphragm 49 is positioned on the underside of the flange 14 having a central bore 82 therein such that the reflector portion 58 and all inner portions of the diaphragm fit within the bore 82. The diaphragm is secured to the flange using a potting compound 84 which may be similar to that which is used to secure the crystal 60 although in this case a quicker curing epoxy may be used. For this purpose a portion of the lower face of the flange 14 may be recessed so as to provide a small space to accommodate the potting compound 84.

In the preferred embodiment the bore 82 is also counterbored from the top (in the drawing) as at 83 to increase the upper space and yet permit adequate mounting of the flange section 50 of the diaphragm to the flange 14. With this accomplished, and the transducer assembly in position, the entire lower portion of the bore 82 above the diaphragm 49 is filled with a lightweight cellular material, preferably a urethane foam of relatively low density and yet relatively rigid in order to suitably protect the diaphragm and its related transducer assembly. The cellular material 88 may be any suitable known urethane foam having a density less than 3.3 lb/ft<sup>3</sup>. Flexible foams may also be used as desired, however, the rigid are preferred in order to provide a suitable back-up for the reflector section 58 and thereby provide an efficient downward reflection of all the sonic waves that are radiated outwardly from the axial portion of the transducer as will be described.

To complete the transducer, a disk-like cover 22 having a central bore 92 is cemented by any suitable cement on the top portion of flange 14. The flange 14 is placed over a mating decoupling or damping washer 94 which preferably may be made of an asbestos Teflon material such as "African Blue" asbestos available from Melrath Gasket. Any other suitable damper may

be used. Peripheral axial bores 96 in the flange 14 and the mating flange 16 are formed to permit the two flanges to be bolted together by suitable bolts 98 (FIG. 1). The flanges may be constructed of fiberglass, iron, steel or any other suitable material.

In the operation of the transducer when an electric field is applied across the annulus of the ring-like crystal 60, the resulting distortion in a radial direction causes sound energy to be radiated outwardly in a radial direction through the wall of the cylindrical portion 51 until it strikes the reflector section 58 at which time it is reflected downwardly into the tank along the axis of the diaphragm to be reflected back up by the interface between the material therein and the air or other gas in the tank. The reflected sound waves are then again reflected now radially inwardly by the reflector section 58 through the wall of the cylindrical portion 51 to again strike the ring-like crystal which converts those sound waves back to electrical signals which are processed by the electrical circuitry of FIG. 2.

To insure optimum operation of the transducer, the cylindrical portion 51 of the diaphragm 49 is constructed of a thickness such that the mass of the crystal per unit reflecting surface area is at least 10 times or more the mass of the wall of the diaphragm cylindrical section per unit surface area so that energy is not needlessly expended in moving the wall of the cylindrical section of the diaphragm. Furthermore, the decoupling section 56, as is seen most clearly in FIG. 6, may be lengthened or shortened in the axial direction so as to have varying lengths to achieve varying amounts of decoupling depending upon the particular lengths and materials employed. If the length becomes too great, the cylindrical portion may wobble and render the transducer unstable. In general, however, the axial length E as seen in FIG. 6 should bear a ratio to the annulus F of the decoupling section which is less than 5 to 1 using normally available plastic materials. With more rigid plastics this ratio may be increased.

This particular design has many advantages. The utilization of the plastic material inhibits the corrosive action of the materials being inventoried on the transducer itself, i.e., the transducer is completely isolated therefrom. The absence of seams solves the corrosion problem noted. By the use of the radiating cylinder and reflecting the radiated sound downward toward the bottom of the vessel, tank or bin, collecting the echo again by means of the reflector permits the exposure of a greater surface area, a thinner cross-sectional area of the crystal can be used than has been feasible heretofore utilizing flat crystals. The use of thinner cross-sectional area is of great advantage inasmuch as it decreases the power required and hence the transducer is safe for utilization even in the presence of possibly inflammable conditions.

The configuration of the diaphragm lends itself to self-cleaning over the entire peripheral surface of the cylinder due to the oscillations of the radiating cylinder. Since the cylinder itself is of recessed construction, the ceramic crystal, which is the most sensitive unit to damage, is quite well protected. Since the diaphragm used is plastic it may be used with many combinations of materials which otherwise might not be able to be used together. The thin walled radiating cylinder insures a low ring time. The side lobes of the crystal are minimized and hence do not give rise to spurious read-

ings. Although the resilient member 78 placed below the transducer crystal is preferred inasmuch as it further reduces ring time, it is not necessary to the proper operation of the unit and may be omitted as desired.

The only real limitation on the axial length of the annular decoupling section is that depending upon the physical strength of the material employed. Obviously, the longer the axial length E (FIG. 6) the greater decoupling effect. On the other hand, as this length decreases, the rigidity of the central cylinder of the diaphragm decreases to the point that there is an unstable condition that can be created and cause pendulum-like vibration of the cylinder portion which is undesirable.

There has thus been described a relatively efficient, unique transducer assembly that is capable of being mounted to transmit sound waves through a pipe, if desired, utilizing any standard pipe connections. The transducer mechanism may be used in the presence of hazardous as well as corrosive materials which could damage the transducer itself. Furthermore, the transducer is quite well protected against damage due to its unique design by which it is potted within the interior of a mounting flange and itself is within a cylindrical enclosure.

It is obvious that many embodiments may be made of this inventive concept, and that many modifications may be made in the embodiments hereinbefore described. Therefore, it is to be understood that all descriptive material herein is to be interpreted merely as illustrative, exemplary and not in a limited sense. It is intended that various modifications which might readily suggest themselves to those skilled in the art be covered by the following claims, as far as the prior art permits.

What is claimed is:

1. A sonar transducer assembly comprising:  
a seamless plastic diaphragm defining a central hollow cylindrical portion having an axis and closed at one end, an outer flange, and an annular reflector section joining the other end of said cylindrical portion and said outer flange and opening in the direction of said closed end,  
a cylindrical transducer positioned coaxially in the cylindrical portion of said diaphragm in radial alignment with at least a portion of said reflector section, and  
means to energize said transducer into radial vibrations, thereby to produce sonic energy which is transmitted through the cylindrical portion and reflected by said reflector section in a direction substantially parallel to said axis.
2. An assembly according to claim 1 wherein the reflector section lies at about a 45° angle relative to said axis.
3. An assembly according to claim 1 wherein said transducer is ring-like, is an electrostrictive material, radiates sound waves radially of said axis, and the mass per unit outer radial surface area of said transducer is more than ten times the mass per unit surface area of said cylindrical portion.
4. An assembly according to claim 1 wherein the other end of said cylindrical portion is curved out-

wardly back on itself to form an annular ring-like decoupling section between said reflector section and said cylindrical portion.

5. An assembly according to claim 4 wherein the curved portion of said decoupling section has a thickness that is less than the thickness of adjoining reflector sections of said diaphragm, thereby to increase its compliance and reduce sound conductivity between said reflector and said transducer.

6. An assembly according to claim 4 wherein the ratio of the axial length of said decoupling section to the annulus of said decoupling section is less than 5 to 1.

7. An assembly according to claim 4 wherein said transducer is ring-like, is secured in said diaphragm by cement, and which also includes damping means positioned on the interior of said transducer.

8. An assembly according to claim 4 wherein:

said transducer is ring-like, is an electrostrictive material, radiates sound waves radially of said axis, and the mass per unit outer surface area of said crystal is more than ten times the mass per unit surface area of said cylindrical portion;

the curved portion of said decoupling section has a thickness that is less than the thickness of the reflecting portion of said diaphragm, thereby to increase its compliance and reduce sound conductivity between said reflector and said transducer; and the ratio of the axial length of said decoupling section to the annulus of said decoupling section is less than 5 to 1.

9. An assembly according to claim 1 which also includes a mounting flange having a central bore therein, said diaphragm being positioned coaxially in said bore and supported by said outer flange, the interior of said bore being filled with a low density, rigid, cellular material thereby to render said reflector more rigid and protect said transducer.

10. An assembly according to claim 9 which also includes an impedance matching transformer positioned within said transducer means.

11. An assembly according to claim 9 wherein said transducer is ring-like, is secured in said diaphragm by cement, and which also includes damping means positioned on the interior of said transducer.

12. An assembly according to claim 1 wherein said diaphragm is made of polytetrafluoroethylene.

13. An assembly according to claim 1 which includes means coupled to said transducer and to said energizing means for determining the time lapse between transmitted sonic energy and echos therefrom returning to said transducer.

14. A sonar transducer assembly comprising:

an integral diaphragm defining a central cavity portion having an axis and closed at one end and an annular reflector section about said cavity portion and opening in the direction of said closed end, and a transducer positioned in said cavity portion and adapted to direct sonic energy radially of said axis through said cavity portion to be generally reflected along said axis by said reflector section.

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