

[54] **CENTER BOLT TYPE ACOUSTIC TRANSDUCER**

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[56]

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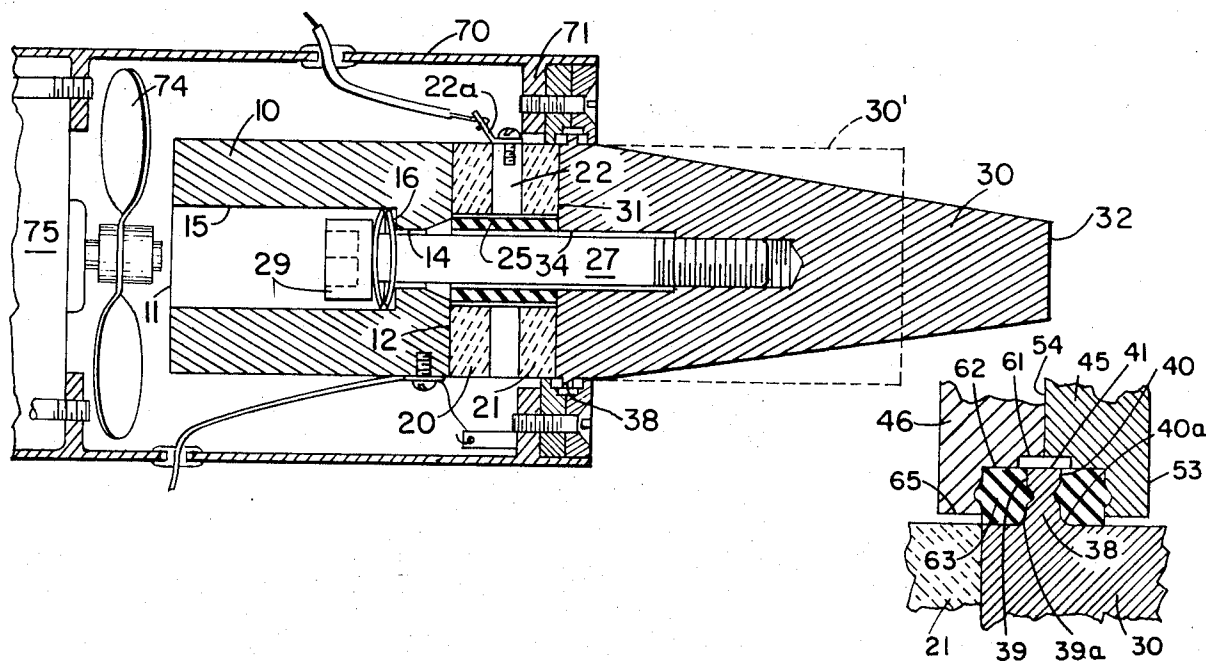
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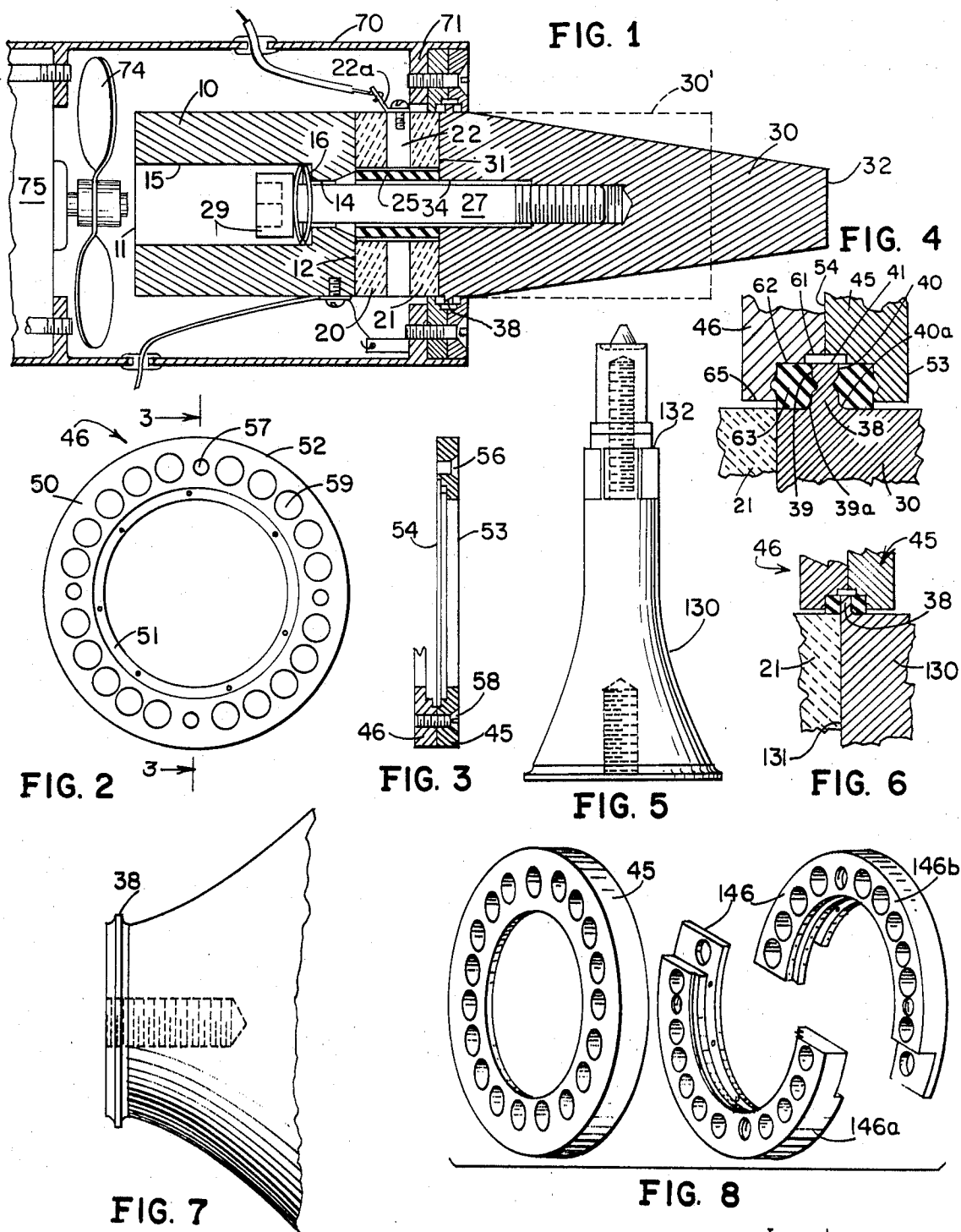
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ABSTRACT

A center bolt type of acoustic transducer has means for mounting such transducer at the nodal plane. This means includes a flange integral with a transducer part and rigid clamping rings cooperating with such flange but acoustically isolated therefrom by suitable gaskets for support. The nodal plane is located at the flange.

5 Claims, 8 Drawing Figures





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CENTER BOLT TYPE ACOUSTIC TRANSDUCER

This invention relates to a center bolt type of acoustic transducer employing flat piezo-electric ceramic plates. A transducer embodying the present invention is capable of operation at moderate levels of power and is sufficiently versatile to function efficiently as a general tool for a variety of work.

The above type of transducer generally consists of a so-called rear slug, usually of metal, and an axially aligned front slug (or horn) between which are disposed a high potential electrode and at least two piezo-electric ceramic plates, hereinafter sometimes referred to merely as "ceramics," but understood to have piezo properties. The assembly is maintained in preset compression by an axial bolt. Such an assembly is generally operated at a suitable frequency (as an example, about 20,000 Hz) for accomplishing various objectives.

Transducers of this general type have problems in connection with interfaces between physically separate parts of a transducer and also in connection with supporting the unit. In addition, such transducers are not susceptible to adaption for various jobs requiring tool change without factory adjustment or redesign. In many instances prior transducers are not adaptable for operating in parallel as part of a battery of transducers without substantial spacing between adjacent transducers. Such spacing is due to mounting requirements of each transducer.

An additional disadvantage of some prior transducers is the inability to change the number of the vibration transmitting half-wave lengths at the front slug (or horn) as may be necessary to apply acoustic energy to a desired work region. A substantial drawback in prior transducers is the number of separate parts (and thus the number of interfaces) required in a transducer unit maintained in preset compression by the axial bolt means. This last named drawback may result in reduced efficiency and definitely in increased manufacturing cost. Opposed faces of separate physical parts of a transducer unit, maintained in compression, must be finished to about one ten thousandth of an inch and involves painstaking and precise preparations of opposed faces.

In many transducers, the mounting of the entire unit on a stationary support results in feedback of static support force to piezo ceramic static compression force and thus affects preset static ceramic compression.

A transducer embodying the present invention has definite advantages over prior transducers. The new transducer has minimum number of interfaces requiring preparation of opposing surfaces; the entire transducer assembly, preset for predetermined piezo ceramic compression need not be disturbed when making a tool change at the work end thereof; the stationary transducer support means is statically independent of static ceramic compression forces; the new transducer permits close spacing between separate parallel transducers and thus permits transducers to operate within minimum space.

A transducer embodying the present invention comprises a high potential flat electrode plate of substantial thickness having flat ceramic plates disposed on opposite sides of the electrode. A rear slug is disposed against one face of a ceramic and a front slug (or horn as required) is disposed against the outer face of the remaining ceramic. A bolt extends axially through the as-

sembly and is pretensioned by internally threaded portions to subject the ceramics to a predetermined operating compression.

For convenience, round ceramic discs are used. The same circular configuration is also used for the elements of an assembly. Except for the ceramics which should not project beyond the metal portions, the outer diameters of the ceramics, electrode plate and rear slug may be the same. The front slug (or horn) will have a circular outer shape, at least at the rear portion thereof. The outer diameter of the front slug at the rear portion thereof will be somewhat greater than that of the adjacent ceramic due to the presence of a mounting flange extending radially from the slug exterior. Otherwise the forward slug (or horn) will have a shape and/or dimensions dictated by engineering considerations. The mounting flange is part of a stationary mount structure.

The mount structure for a transducer provides a highly efficient and effective support means. The transducer mount is such that the static weight or load pressure of a transducer unit will not result in any change of pre-compression upon the ceramics, thus isolating the static preset force of compression on the ceramics from the mounting of a transducer with relation to work. The annular support flange for a transducer projects laterally beyond the remaining peripheral parts of the transducer. The extent of support flange projection is quite small so that the entire transducer has minimum requirements for mounting space.

The new transducer has its vibratory output longitudinally of the transducer assembly. The nodal plane is normal to the transducer axis at the annular flange and has minimum vibratory amplitude. Longitudinally in either direction from the nodal plane the amplitude of longitudinal vibration increases to a maximum along the transducer axis at a region one-fourth of a wave length away from the nodal plane and thereafter decreases further away from the first nodal plane until one-fourth of a wave length from the maximum or peak amplitude there is a new nodal plane. As a rule, a transducer generally extends only for one-fourth wave length to the non-working rear end thereof. The front (working) portion is dimensioned to be some desirable number of odd one-fourth wave lengths from the center of the nodal flange.

In the new transducer, the nodal plane is located near the rear of the forward slug (or horn). In this new construction, the front slug (or horn) is always somewhat longer than one-fourth wave length (or odd multiple thereof).

The location of the nodal plane forwardly of the ceramic assembly has a number of advantages. The design of the transducer mount structure is quite flexible and lends itself to accommodating various shapes of transducer housings. The housing may be designed to provide protection for high and ground potential leads; to insure adequate dissipation of heat; to support the housing and transducer in desired relation to the work; and in general to isolate the static load on the work from the static load on the ceramics.

A transducer assembly inherently has interfaces between dissimilar solid materials having different acoustic impedances. Vibratory energy travelling along a path through one solid medium and encountering a different solid medium invariably suffers a transmission loss in the form of backwardly reflected waves. In a homogeneous solid medium, the interlinking of crystals

makes for minimum transmission losses. However, where the nature of a solid medium changes, as between ceramic and metal, or between two different metals, then the effectiveness of energy transmission will depend upon the relative complex acoustic impedances of the materials and how intimately the solid materials on opposite sides of an interface can be in physical contact with each other. The smoother and flatter the opposed faces are, the less air space there will be between the two solids. 100 percent is a theoretical ideal which cannot be attained. Careful surface preparation can come close to the ideal so that transmission of wave energy through an interface may reach a value of the order of about 90 or 95 percent. Grease "couplants" are sometimes used. It is obvious that successive interfaces in a wave transmission path can rapidly cut down overall transmission efficiency, especially if the facing surfaces are not smooth and flat.

A ceramic disc is available with a very thin silver coating on each face originally put on for "poling" purposes during manufacturing. The face is usually smooth and true to about a few tenths of a thousandth of an inch. The bond between silver and ceramic is good enough so that the silver coating may be retained.

Practical considerations dictate the use of a high potential electrode having substantial thickness. The new transducer embodying the present invention has a minimum number of interfaces. These interfaces are on both sides of each of two ceramic discs. Having a high potential relatively thick metal electrode disc minimizes some lead assembly problems for applying potential to the ceramics.

The new transducer assembly in general includes forward and rear slugs between which is disposed the ceramic containing portion of the assembly. This portion comprises two ceramic discs properly poled and having a common high potential electrode between them. Axially within the slugs, ceramic discs and intervening electrode is a bolt for maintaining the transducer assembly at a predetermined compression. The bolt referred to is frequently designated as a cap screw, but for convenience, the word bolt will be used herein.

The rear slug (which may be of a suitable solid) is preferably of steel or other dense metal and with the ceramics and high potential electrode extends for somewhat less than one-fourth wave length at the desired operating frequency. The nodal plane is theoretically established near the rear end of, but within, the forward slug, ideally the center plane of flange thickness. It is understood that the total physical length of the parts will depend on the frequency at which the transducer is to be operated. In the new transducer, while structural details are not dependent upon any particular frequency, where appropriate the specific figures or discussion will be in connection with a system for operation at or about twenty thousand cycles per second (20KHz). The ceramics may be discs having a thickness of the order of about one-fourth inch, the outer diameter substantially $1\frac{1}{2}$ inches with an axial hole therethrough having a diameter of about one-half inch for accommodating a compression bolt. The rear slug is cylindrical and has its outer diameter equal to that of the ceramics. The front slug is of suitable matter, as titanium or high strength aluminum, and may be cylindrical or, except for the rear portion, non-cylindrical, depending upon engineering considerations. As is well known in this art, from the rear face

of the forward slug the forward working slug (or horn) may vary toward the working or tool end in cross sectional area and shape, as exponential, catenoidal, linear, etc., horn profiles, all well known and fully set forth in published literature, to provide desired operating characteristics at the tool end.

The ceramic material may be anyone of a number of materials well known in the art and available on the market. Presently, ceramic materials are of barium titanate, lead zirconate titanate and other related compounds. These materials are desirable because they can withstand moderately high temperatures; have suitable electrical properties; are available at relatively low cost and have acceptable mechanical properties. As a rule, ceramics can withstand considerable compression forces but are weak in tension. Thus, any force tending to bend a ceramic plate (due, for example, to improper matching of faces of ceramic and metal) will result in fracture of a ceramic plate.

In considering the assembly of high potential electrode, ceramics and slugs, maintained in predetermined compression by an axial bolt, the term rear slug or resonator may be used to describe a cylindrical member. Forwardly of the ceramic plates, the member may be designated as a front slug or resonator or horn depending upon its function. Generally, slug or resonator are frequently used interchangeably where the member has a generally cylindrical shape and a constant outer diameter. The same is true of the rear slug or resonator. However, unlike the rear slug or resonator, the forward functioning member may not only have a wave transmission function, but also a wave amplitude function in which case such member is usually designated as a horn.

Where forwardly of the ceramic array it is necessary to have a long energy path to the tool tip (as in working inside of long pipes), additional multiples of half wave may be provided bolted together to extend the energy conducting path by an integral number of additional half waves. The tool slug (or horn) will be at the end. Path extending slugs may be cylindrical with all amplitude transforming functions concentrated in the end working horn carrying the tool or there may be impedance transforming sections. The slugs on both ceramic faces are provided with axial passages or recesses for accommodating a bolt for maintaining an assembly in compressed condition.

In accordance with the invention, an improved supporting means at a nodal plane is provided. The nature and location of means supporting a transducer assembly is important because this may represent a drain of acoustic power from the transducer.

The invention will now be described in connection with the drawings wherein

FIG. 1 is a view in section for the most part with certain parts being shown in elevation of a transducer unit embodying present invention, the unit being mounted in a housing, the transducer unit being provided with a tapering horn, shown in section, and a front slug, as a modification, shown in dotted lines.

FIG. 2 is a side elevation of a mounting ring for the transducer.

FIG. 3 is a view on line 3—3 of FIG. 2 showing two mounting rings for a transducer.

FIG. 4 is an enlarged detail of the mounting rings and gaskets.

FIG. 5 is an elevation of a front horn having a modified gasket support.

FIG. 6 is an enlarged detail illustrating the modified gasket support of FIG. 5 in an assembled transducer.

FIG. 7 is a detail of an outwardly tapering horn which may be used with the new transducer.

FIG. 8 is an exploded view showing a two piece clamping ring for use with the general horn arrangement illustrated in FIG. 7, the rings being shown in exaggerated form to illustrate the mechanical construction.

Referring to the drawings, the transducer includes back or rear slug 10 having flat end faces 11 and 12. Slug 10 preferably is cylindrical with axial bore 14 and counter-bore portion 15. The counter-bore extends from free end face 11 for a part of the slug length to internal flat annular shoulder 16. The location of shoulder 16 with respect to the slug length is not critical for general applications and it may be located about two-thirds of way between slug end faces 11 and 12, as shown. The longitudinal location of shoulder 16 will be determined in substantial measure by acoustic and mechanical considerations including the length of the compression bolt to be used, its diameter, modulus of elasticity, strength, etc. The radial dimension of shoulder 16 will be determined by mechanical engineering requirements including clearance for the size of the bolt head, or for washer diameters if used. The diameter of bore 14 will be determined by the diameter of the bolt shank or for other desired clearances while the outer diameter of slug 10 will be determined by the outer diameter of the ceramic discs.

In cases where a transducer is required having high vibrating amplitudes at the forward face and broad-band (low Q) resonance characteristics, then the choice of backslug material is important. In such cases, the backslug material should have a high acoustic impedance as compared to the forward slug. As is well known in the art, this material impedance depends on a large degree on its density and velocity of propagation. End face 11 and the outer surface of rear slug 10 require no special finish other than rust protection. The same is true of the surfaces of bore 14 and counter-bore 15. Shoulder 16 however should be finished to a smooth flat surface perpendicular to the slug axis and accurate to about one thousandth of an inch.

Slug end face 12 which abuts a ceramic face must be carefully prepared. The faces of ceramics should be flat to within one or two ten thousandths of an inch and must be truly normal to the axis of the ceramic discs. End face 12 of slug 10 must also be perpendicular to the axis of slug 10 and must also be true to the same degree as the ceramic face. The surface of face 12 is preferably lapped but need not be highly polished. A satin or etched surface will suffice. In preparing face 12, the fact that face 12 will be tightly pressed against a ceramic face must be kept in mind. Good results have been obtained in finishing surface 12 on a precision surface grinder using an accurately dressed, fine stone wheel. The ceramic material can resist compressive forces of great magnitude. However, such ceramic materials are brittle and will crack unless the matching surfaces are accurate. Some "coining" of the silver coating on ceramics fills in microscopic irregularities under the compressive forces used.

Referring now to the ceramics, two discs 20 and 21 have disposed between them high potential metal disc

electrode 22. As is well known, ceramics 20 and 21 are poled so that the appropriate faces are in the right direction. The polarities of the two ceramics are such that when a high electric potential is applied across the faces of each ceramic (the ceramic faces are electrically connected in parallel) the reaction of the ceramics are mechanically aiding so that essentially the two ceramics are in series mechanical relation. This arrangement is well known in the art.

High potential electrode 22 consists of a metal disc having a thickness of the order of about 3/16 of an inch. Electrode 22 may be of any desired electrically conducting material such as aluminum, brass, steel, etc., and has its opposite faces finished to the same degree of accuracy as end face 12 of rear metal slug 10. Electrode disc 22 is thick enough to provide support for electrical terminal 22a to which an insulated electrical conductor may be connected. The ceramic assembly, including ceramics 20 and 21 and intervening electrode 22 have the same outer and inner diameters. The inner diameter of the parts making up the ceramic assembly is preferably somewhat larger than the diameter of bore 14 of rear slug 10 to accommodate tubular insulator 25, disposed between the inner surfaces of the ceramics and electrode on the one hand and outer surface of bolt 27 passing through rear slug 10 and within insulator 25. Insulator 25 is made of material which is a good electrical insulator and can withstand a reasonable degree of heat and ultrasonic vibration. As an example, insulator tube 25 may be of teflon or silicone rubber or fiberglass. Each of these insulating materials can withstand temperatures of the order of about 500°

F. Buna N and Neoprene rubber may also be used in lower power units.

Ceramics now available can withstand temperatures of about 400° - 500° F. without undue depolarization. The potentials used on ceramics are normally of the order of four or five hundred volts for this type of structure. As a rule the dielectric constant of the insulator is not important since the operating frequencies, usually about 20KHz, are too low to result in dielectric losses of any magnitude.

Bolt 27 is threaded along as much of the bolt length as necessary to insure a firm grip with the internally threaded part of, in this instance, a front horn.

Bolt 27 must have an overall length such that the bolt head at one end and threaded portion at the other end are well spaced from the ceramic assembly and the nodal plane region beyond ceramic 21, to be described later. When a transducer assembly is ready for operation, bolt 27 has a static tension which is uniform along the bolt length. In transducer operation, dynamic conditions in the transducer result in superimposing on bolt 27 added tensile forces which may increase or decrease the normal bolt static tension. (It is understood that bolt 27 should not have its tension reduced to zero at any time.) When bolt 27 is subject to dynamic loading, it is stressed to maximum values along its length and near the transducer nodal plane and should have maximum metal to resist tension. Hence it is desirable to have the threaded bolt part well spaced as pointed out. The threaded bolt part however must be long enough so that a strong coupling through the bolt threads can be provided. As an example for the dimensions of ceramics given, the threading should be about one-half or three-fourths inches long.

Bolt 27 fits loosely within smooth bore 14 of rear slug 10 and the bolt has head 29 dimensioned to fit within bore 15 of slug 10. Bolt head 29 is generally of the internally wrenching type as the so-called Allen type having a recessed hex so that a hexagonal rod may be used to torque up the bolt. As is usual in this art, bolt 27 may be of high strength steel, or other fatigue resistant materials, which can withstand a high tensile force used for compressing crystals 20 and 21.

As previously set forth, bolt 27 is maintained in tension to a predetermined value, about which value dynamic conditions incident to acoustic transducer operation result in transient increase or decrease of static bolt tension. It is desirable that the static tension operating point be maintained at a constant value over variations in temperature which might result in variations of bolt length. Conical spring washers (Belleville) are provided for this purpose and for convenience, one or more such washers are disposed between the bolthead and shoulder 16 created by counterbore 15 at the inner end thereof. If more than one such conical spring washer is used, they may be arranged in any desired fashion (large end opposed; small ends opposed) depending upon washer characteristics. Such use of conical spring washer or washers maintains a substantially constant bolt tension for static conditions in spite of ambient temperature conditions.

Referring to tubular insulation 25, it is desirable that this fit as snugly as possible to the inner surfaces of ceramics 20 and 21 and electrode 22. Insofar as bolt 27 is concerned, it is selected to be of a length and having elastic properties consistent with engineering requirements involved in tensioning the bolt to obtain the desired amount of compression upon the ceramic assembly. It is also desirable to have the diameter of bolt 27 as small as possible and the diameter of head 29 as small as possible. While the tension in bolt 27 serves to compress ceramics 20 and 21 on opposite sides of high potential electrode 22, bolt 27 essentially is a foreign but very necessary element. Care must be taken to avoid excessive bolt length so that the resonant frequency of the bolt is not too close to the resonant frequency of the transducer assembly. This will minimize the interference between the acoustic energy of the transducer proper and acoustic energy within bolt 27.

Bolted tightly to the threaded end portion of bolt 27 is forward horn 30 of suitable metal such as hard aluminum, titanium alloy or any other material having desirable acoustic transmission properties as well as having sufficient toughness to withstand wear and tear. As shown here, horn 30 has a tapered exterior surface with rear face 31 and forward end face 32. Horn 30 has blind axial recess 34 conveniently threaded at the forward part of the recess. End face 31 of the horn presses against the outer face of ceramic 21 and accordingly requires a finished face which is true and accurate to the same degree as face 12 of rear slug 10. Bolt 27 has an unthreaded part of its length extending forwardly of rear horn face 31 in a counter-bored rear portion of horn recess 34. The threaded end portion of bolt 27 engages the blind threaded end portion of horn 30 to permit horn 30 to be tightened on bolt 27 enough to tension bolt 27 to a prescribed value for compressing the ceramics.

In assembling the transducer, it is preferred to dis-
pose the rear slug, ceramics, including the high potential electrode, and horn in jigs to keep them in desired

relative position while restraining them against relative rotation to minimize torsional effects in ceramics. The bolt and conical washer (or washers) are then disposed in proper position and the bolt head is then turned to create the desired bolt tension.

Front member 30 as illustrated in FIG. 1, is a horn whose small forward end may function as a tool or may actually carry a tool for applying acoustic energy to a load. Such a horn construction, insofar as its forward end is concerned, is conventional.

Instead of horn 30, a cylindrical slug 30' shown in dotted outline, may be used. Slug 30' will require the addition of suitable tool members. Slug 30' will usually be shorter than horn 30. No attempt has been made to show parts to scale. In all instances, the rear part of the front member (horn or slug) will always have a cylindrical portion 31. If slug 30' is used, it may be desirable to have a bore through the entire slug length or have a threaded recess at the forward end of the slug, generally similar to FIG. 5 extending forwardly of rear face 31 and carrying flange 38 integral with member 30 or 30'. The overall length of the rear slug and ceramic assembly on the one hand and length of front member 30 (or 30') on the other hand are such that the nodal plane is located at flange 38, preferably the mid plane of flange 38, perpendicular to the transducer axis. This means that front member 30 (or 30') will have an overall length greater than one fourth of a wave length, since that portion of the front member between rear end face 31 and half of the flange thickness will constitute part of the rear one fourth wave length of the transducer system.

Flange 38 preferably has a rectangular cross section providing side walls 39 and 40 and peripheral outer wall 41. Flange 38 has a thickness along the length of member 30 which is small in terms of operating wave length but thick enough to be strong. Side walls 39 and 40 have curved fillets 39a and 40a where the metal runs into the body of member 30. As an example, the transducer so far described may have flange 38 about 1/32 of an inch in thickness. The width radially of flange 38 may be any desired value and theoretically this flange could extend outwardly for an indefinite distance. This is because the nodal plane is located between side walls 39 and 40 of this flange and thus the metal at or near the nodal plane has substantially no longitudinal movement. For short distances away from the nodal plane the amount of longitudinal movement may be considered to be negligible. Consistent with mechanical support requirements, the thickness of flange 38 should be a minimum.

The entire transducer assembly is supported on opposite sides of flange 38 by rings 45 and 46 of strong, rigid material, such as aluminum. For the most part, rings 45 and 46 are alike, each having body portion 50 and inner gripping or clamping portion 51. For convenience, body portion 50 is ring shaped with outer circular edge 52. The thickness of each ring may vary and as an example, for the transducer described, the thickness of each ring may be about five thirty seconds of an inch. The radial dimension of each ring (the difference between the inner and outer ring edges) may also vary widely and will depend upon mechanical considerations. As an example, the distance between the inner and outer ring edges may be about one-half inch. Each ring has outer face 53 and inner face 54, the two rings

normally being clamped tightly with inner faces 54 being in contact with each other.

To maintain rings 45 and 46 in tightly abutting face-to-face relation, one of the rings, as 45 for example, has its body portion 50 provided with counter-sunk holes 56 and the other ring has threaded holes 57, which register with counter-sunk holes 56 to accommodate screws 58. As illustrated herein four such registering sets of holes equally spaced around body 50 of each of the two rings is provided. The remainder of body 50 of each of the rings has closely spaced registering holes 59 to permit air to pass through from one side of the two rings to the other side thereof. As will be explained later, the entire transducer may be mounted within a housing and rings 45 and 46, in the absence of holes 59, would impede movement of air along the length of the transducer assembly.

The diameters of holes 59 and the spacing between adjacent holes are not critical. Instead of holes through the body of the two rings, the outer edges of the two rings as assembled may be scalloped to promote the passage of air through or past the rings. The two rings are preferably made of aluminum, although brass, steel or other material as non-metal may be used.

The construction of clamping inner portion 51 of each ring will now be described. Rings 45 and 46 may have identical inner clamping portions. The inside surface of clamping portion 51 of each ring has a series of flat steps. Beginning with inner face 54 of each ring, first step 61 has the maximum diameter and is large enough to clear by a small fraction of an inch outer surface 41 of flange 38. The axial dimension of each step 61 is more than one half the thickness between flange side walls 39 and 40 as suggested in FIG. 4, sufficiently so that ring metal and flange metal will never touch. When two rings are clamped together tightly, both steps 61 cooperate to encircle outer wall 41 of flange 38 having an annular clearance such as about fifteen thousandths of an inch for the example given. Next step 62 is dimensioned to engage the outer surface of O-ring gasket 63 having a rectangular cross section. Each clamping ring 45 and 46 cooperates with each of the two O-rings 63. Ring 63 is of compressible or deformable material which can withstand substantial heat and will not break down from acoustic energy. As an example, such materials as silicone rubber, Teflon, Buna-N and neoprene rubbers may be used. The normal cross section of gaskets 63 is preferably rectangular and dimensions are such that when the parts are assembled, adequate compression results with substantially full contact between gasket surfaces and metal established. It is possible to use O-rings of circular section and correspondingly shape the surfaces engaging the gasket.

It is important that relative rotary movement between the transducer proper and its mounting be prevented. Such movement might be at the surfaces of metal and material of gaskets 63. Rotary movement there could result in broken wire leads. To avoid such movement, it is possible to interlock the gasket material and metal pressed against such gasket material. Thus side walls 39 and 40 of flange 38 could have indentations in the metal surface or fine passages through the flange from one side wall to the other side wall of the flange. Sharp edges in the metal should be avoided. Similarly, the metal of ring parts 45 and 46 (or the corresponding parts of the ring modifications) can be similarly treated so that the gasket, under compression, will

be locked against rotary movement when the transducer is assembled. The O-ring gaskets may be positioned on each flange side at an appropriate time, when assembling, and cemented if desired.

The compression of the gasket material should be limited to avoid increasing conductivity of gasket material to acoustic energy to an undesirably high level. So long as the gasket material is soft enough to permit relative play of the transducer and the mounting, the gaskets, particularly in view of their proximity to the nodal plane, will essentially isolate the transducer from acoustic energy leakage at the mounting and prevent destruction of the mounting system.

Step 65 is at the outer face 53 of each ring and has the minimum inside diameter for each mounting ring. Gaskets 63 are normally quite soft (for example a Durometer value of about 50 may be used) but compression is sufficient to make the suspension stiff enough to be workable. In any event, clearances and suspension stiffness are such that any acoustic coupling from the transducer to the mounting ring is via the gaskets only.

For a transducer operating at approximately 20 KHz, a 1½ inch diameter steel rear slug may have an overall length of about 1½ inches, a forward aluminum 1½ inch slug may have an overall length of about 2¼ inches, two ceramics each about one-fourth inch thick and a high potential electrode about 7/32 inches thick may make up a trasducer having a half wave length of a bit over 4½ inches. It is understood of course that the dimensions may vary with design parameters. The nodal plane will be predetermined to be at the flange mid section near the rear of the forward member.

Instead of having a forward horn 130 carry a tool at end 132, as shown in FIG. 5, it is possible to add a resonant extension of proper material, proper length and suitable acoustic impedance characteristics.

The front member 30 (or 30') illustrated in FIG. 1, has flange 38 spaced away from end face 31 by substantially the thickness of a gasket. This enables both gaskets to be positioned accurately on opposite sides of flange 38 on the same member prior to assembling clamping rings 45 and 46.

It is possible, however, to have flange 38 at the rear end of the forward member so that a flange side wall is part of end face 31. This is illustrated in FIGS. 5 and 6 which show a front member 130. In this front member, the rear end portion of member 130 will be cylindrical, even though the remainder thereof may have any desired shape. One gasket ring will overlie the cylindrical portion of member 130 forwardly of flange 38 while the companion gasket ring will be disposed about the forward cylindrical end of the ceramic part 21 of the system. When the outer clamping rings are applied to each of the two gaskets in the form just described, it is possible that one gasket may tend to be eccentric with respect to the other gasket so that somewhat greater care in assembling the entire structure may be required.

A housing for a transducer assembly will generally be a practical necessity over the rear portion of the transducer beginning with the mounting rings and extending rearwardly over the ceramics, high potential electrode and rear slug. A simple housing 70 of generally cylindrical construction may be provided. Housing 70 may either be of synthetic material as plastic or may be of metal such as aluminum of sufficiently heavy gauge to withstand rough use. While a housing may be cylindri-

cal, there is no particular necessity for such a shape and, instead, the housing may have a rectangular cross section. This, of course, would require a different shape for the outer edges of the mounting rings or might require some adapter between the inside surface of the housing and the outer portion of the mounting rings.

A simple mounting for a transducer within housing 70 may have an inwardly extending shoulder 71. The inside diameter of housing 70 may be large enough to accommodate the outer edge of the mounting rings while inner shoulder 71 would provide a support against which the mounting rings may be disposed and to which they could be attached. As an example, inner shoulders 71 may be of aluminum and have a series of holes registering with the holes in the mounting rings. Retaining bolts may be used at a number of such holes to attach the mounting rings to the housing shoulder. Any other attaching means between housing 70 and the mounting rings of a transducer may be used.

It may be desirable to provide a blast of cooling air for dissipating any heat generated by the transducer unit. The direction of flow of such a blast of air is preferably rearwardly of the transducer beginning about at the mounting rings and extending within the housing past the rear free end of the transducer. By having the blast of air travel in that direction, there will be less likelihood of air blasts on the work with consequent blowing of fine particles. The air blast itself may be provided in a number of ways as for example by fan 74 driven by electric motor 75 supported within the housing. It is understood, of course, that the rear end of the housing will be open to the atmosphere so that a continuous blast of air may travel through the holes in the mounting rings and over the exposed surfaces of the ceramics, high potential electrode and rear slug.

Suitable wire leads for the electric motor, the grounded rear slug, forward member or whatever metal parts are used forwardly, mounting rings and housing, if of metal, are disposed within the housing. A lead from the high potential electrode and a ground wire from the mounting ring (if such mounting rings are electrically insulated from the housing interior as would be the case in a housing of plastic material) must be carefully located on the transducer as close to the nodal plane as possible. Precautions conventional in this art to prevent crystallization of wire are followed.

The mounting of a transducer may, in some instances, require some differences in the mechanical construction of the mounting rings. For example, rings 45 and 46 are circularly continuous. However, it is possible to have a mounting ring assembly where a ring is divided into two semi-circular portions each of which essentially integrates half ring 146a and half ring 146b to extend over the edge of flange 38. The two semicircular ring portions may be bolted together by overlapping extensions as illustrated in FIG. 8. In certain instances it may be desirable to have one of the mounting rings — the one nearest to the outer surface of the ceramic — circularly continuous and have a cooperating ring divided into two semicircular parts. Such an arrangement is required for a horn shown in FIG. 7, where the metal forwardly of flange 38 is outwardly expanding so that a continuous ring cannot be used. In such instances, a one-piece ring may be used on one side of the flange and a composite split ring may be positioned on the other side of the flange. The gaskets have sufficient elasticity to be stretched over a flange.

Referring specifically to FIG. 8, one mounting ring, in this case 45, is circumferentially continuous and is provided with suitable holes through the ring. This solid ring has a stepped interior generally similar to the stepped interior of one of the two rings illustrated in FIGS. 3 and 4. Solid ring 45 is adapted to go about the cylindrical end of a horn such as, for example, shown in FIG. 7 on the side of the flange nearest the small end face of the horn.

Split ring 146 has portions 146a and 146b which provide generally semi-circular rear portions. At the split, the ring ends are stepped as shown so that two semicircular rings may be fitted to make a complete ring. It is clear that the split ring may be disposed about the narrow annular cylindrical surface of the horn adjacent the flange but located on the far side of said flange away from rear end of the horn. By screwing or bolting the various parts or the ring portions together, the entire mounting assembly for a horn, such as illustrated in FIG. 7, may be provided to accommodate an outwardly flaring horn surface.

Other ring splitting procedures may be adopted to permit mounting of a transducer assembly for work.

It will be clear that the invention provides a transducer assembly whose lateral mounting space requirements are minimized. Thus, a transducer assembly of the type illustrated in the drawing (with or without the housing as desired) may be disposed in close proximity to similar transducers. The only clearance between adjacent transducers is normally determined by the radial extension of the flange beyond the outer surfaces of the transducer. Such economy of mounting space permits of close disposition and operation of a plurality of transducers. No attempt is made to show relative proportions of radial dimensions of a transducer mounting flange and the transducer proper. It is obvious that a number of transducers can be mounted side by side on a plate and so closely spaced that the outer flange diameters nearly touch.

It is possible to remove flange portions between adjacent transducers to permit closer transducer spacing of a cluster of transducers. Thus, instead of a 360° continuous flange mounting, cutouts of metal and gasket portions over small arcuate regions about a transducer permit minimum spacing between transducers for maximum application of acoustic energy at a given locale.

I claim:

1. An ultrasonic transducer comprising two piezoelectric ceramic discs with a high potential electrode therebetween arranged to form a stack, said ceramic discs having flat surfaces, electrically grounded front and rear acoustic resonators axially aligned with said stack and having conforming shapes and at least equal areas cooperating with the flat disc surfaces, axially disposed bolt means for retaining as an assembly said resonators and said stack under predetermined compression, said front resonator having its rear-end portion shaped so that sections transverse to the resonator axis are circular, and the front end thereof being adapted to feed ultrasonic energy for work, said rear end portion having an integral outwardly extending uniformly thick support flange having a thickness along the front resonator length which is small in terms of operating wave length but thick enough to be strong, said transducer having a nodal plane at the flange; mating rigid rings disposed at opposite sides of said flange, a readily com-

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pressible heat resistant gasket ring at each side of said support flange, each said gasket ring contacting substantially all of the opposed surfaces of said flange sides and portions of said rigid rings and also contacting outer surfaces of the transducer's said assembly parts adjacent the flange, means for supporting said rigid rings in predetermined spaced relationship, said rigid rings forming part of a mount for the entire transducer assembly, said rigid rings having sufficient clearance with respect to the body of said transducer's said assembly parts to accommodate limited vibration isolation at said gasket rings consistent with mounting rigidity between the transducer assembly and said rigid rings, the generally distributed compression of gasket rings between gasket compressing surfaces preventing the formation of destructive localized hot spots in said gasket material; said transducer having minimum interfaces to minimize interface losses and the flange transmitting directly to said front resonator load pressure without significantly affecting the nature or distribution of the predetermined compression force on the ceramics and without increasing the bolt tension significantly.

2. The construction according to claim 1 wherein said flange is located forwardly of the rear end face of

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the front resonator so that said two gasket rings may be disposed on opposite sides of the flange about the rear end portion of said front resonator.

3. The construction according to claim 1 wherein at least one of the surfaces against which a gasket is compressed has relatively small irregularities for frictionally locking the adjacent gasket material against relative movement whereby a gasket is prevented from moving with respect to the transducer about the axis of said transducer assembly.

4. The construction according to claim 1 wherein said flange is located so that one sidewall thereof forms an extension of the rear end of said front resonator with one gasket overlying the adjacent end of a ceramic.

5. The construction according to claim 1 wherein said front resonator tapers from its flanged rear end portion with said resonator cross sectional area decreasing as the front end is approached, said front resonator having a length somewhat in excess of one-quarter wave length, said front end of said front resonator providing a mechanical advantage in amplitude increase whereby a compact transducer structure is provided.

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