

[54] SONIC TRANSDUCER

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310/26

References Cited

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3,578,996	5/1971	Balamuth	310/8.2 X

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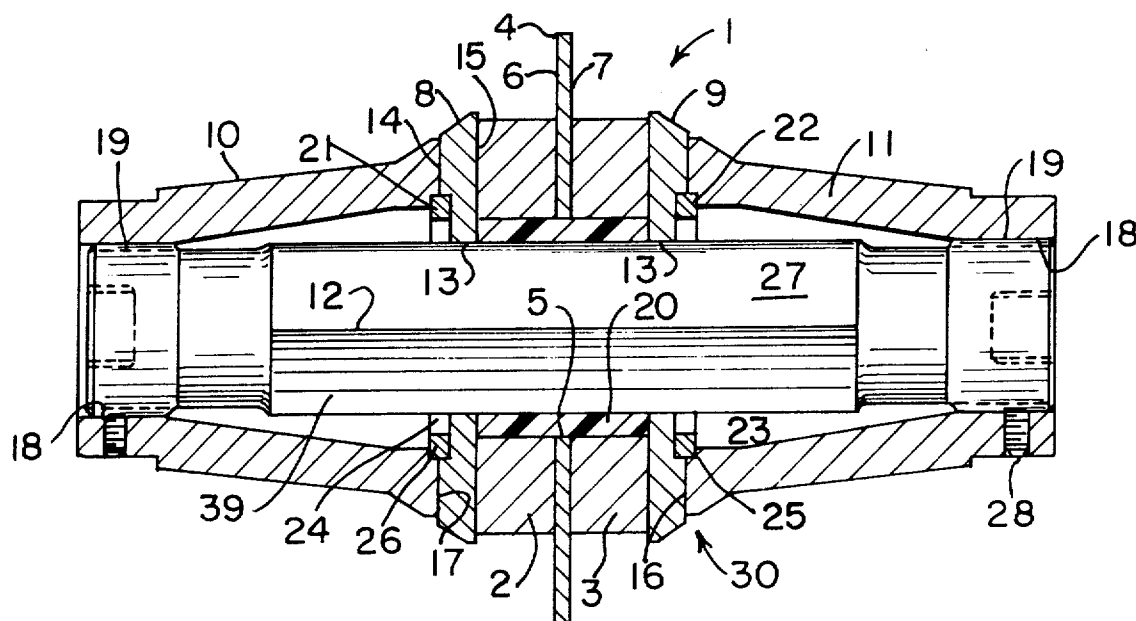
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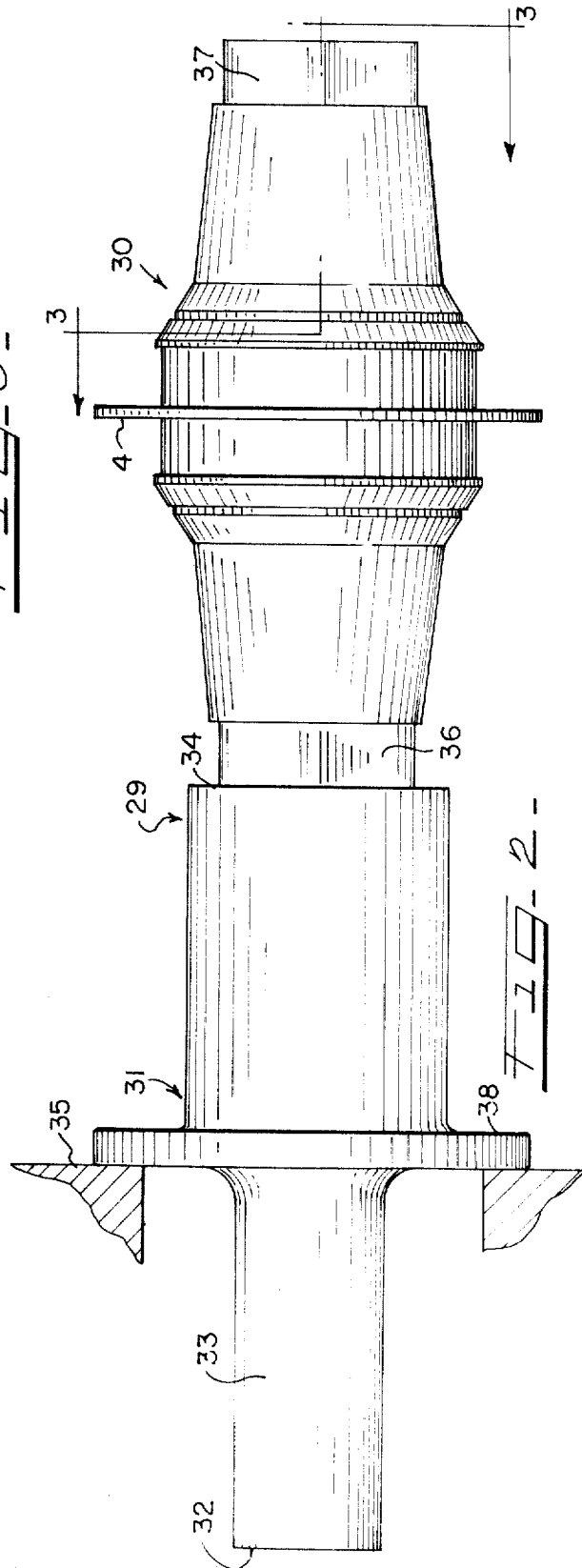
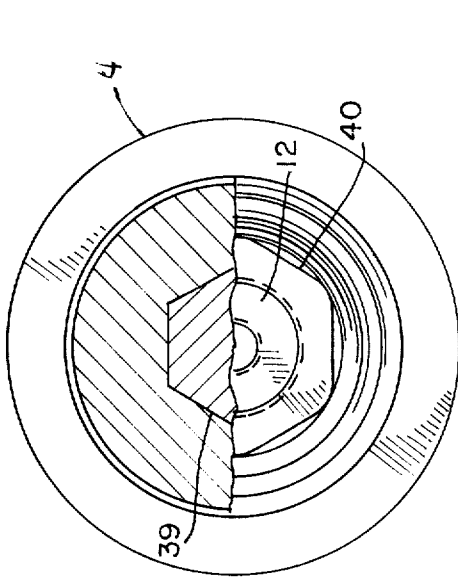
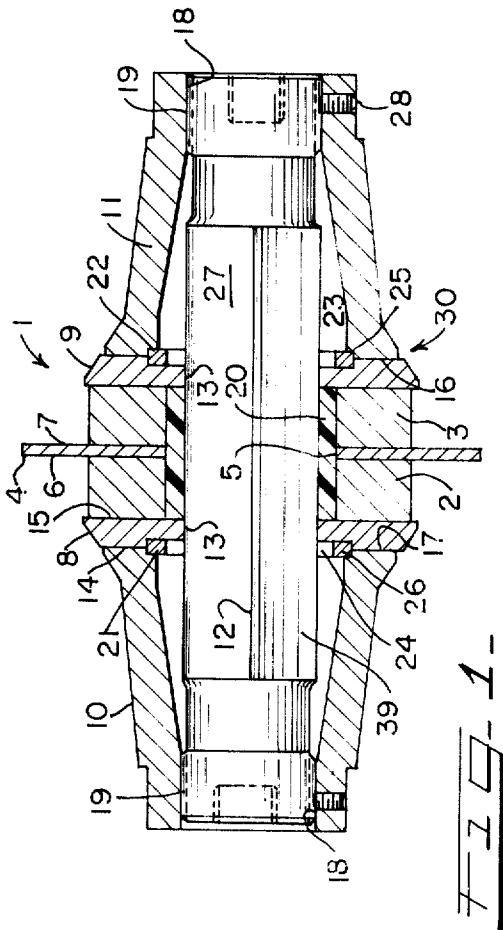
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ABSTRACT

My invention is a transducer having a resonating element and a power generating element. The acoustic length of the resonating element is made the same as the acoustic length of the power generating element. Each is made to be a length one half wave ($\lambda/2$) when the transducer operates at a given frequency. In this way, the ends of the resonating element and the power generating element are attached to each other and there is little stress at the point of attachment.

12 Claims, 3 Drawing Figures





SONIC TRANSDUCER

CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation of copending application Ser. No. 203,587, filed Dec. 1, 1971 and now abandoned.

This invention relates to ultrasonic transducers and pertains to a novel form of transducer for transforming electrical energy into ultrasonic energy.

In the last decade, many sonic and ultrasonic transducers have been proposed. Typical of these are the patents to James Byron Jones et al., U.S. Pat. No. 3,283,182; John N. Antonevich, U.S. Pat. No. 3,370,186; and Lewis Balamuth, U.S. Pat. No. 3,578,996. These devices use a shaft or sleeve to hold the transducer in compression. The devices developed, so far as known in the art, have usually had large stresses at the point of attachment between the shaft and the resonating end of the transducer. A shaft is ordinarily a stud or screw used to pull the elements of the transducer together so that the electrostrictive elements are placed in initial compression. Transducer failure is frequent in the area where the threads of the stud match with threads in the power generation part of the transducer itself.

It is an object of my invention to provide a transducer having a maximum displacement amplitude at its ends.

It is a further object of my invention to provide a transducer wherein the stress at the end threads is minimized.

It is a final object of my invention to provide a transducer wherein the power generating assembly is of the same acoustic length as the resonant tensioning stud.

In brief, my invention is a transducer assembly having a resonating stud and a power generating assembly. The acoustic length of the resonating stud is made the same as the acoustic length of the power generating assembly. Each is constructed to be of length equal to one half wave ($\lambda/2$) if the transducer operates at a given constant frequency. In this way, the ends of the resonating stud and the ends of the power generating element may be attached to each other with little dynamic stress at the points of attachment during operation.

A better understanding of an embodiment of my invention may be had by reference to the accompanying illustrations and the following description wherein like reference numerals refer to like parts.

FIG. 1 shows a cross-sectional view of a transducer of my invention.

FIG. 2 shows a horn attached to my transducer.

FIG. 3 shows a cross-sectional view of my transducer taken along the line 2—2 of FIG. 2.

The principles of my invention are applicable to more than one type of transducer. However, shown in FIG. 1 is an embodiment of my invention. The transducer of FIG. 1 has a central stud mounted so that it passes through the other elements of the transducer assembly and binds them together under a compressive force. When assembled, the stud itself is in tension. This stud is made of a material which can stand considerable tensile force, such as steel.

Threads are cut into the exterior surface of the stud at each end of the stud. These threads lock with internal threads of the tubular means which is part of the force generating assembly. A section of this stud next

to the threaded section is undercut to an amount slightly in excess of the depth of the thread and extends part way toward the center of the stud. The purpose of this undercut is to avoid the stress concentration which exists at the termination of a thread when that termination occurs within the body of the stud.

In the ordinary transducer assembly, considerable stresses are applied to the threads of a stud such as the stud shown in FIGS. 1-3. Every sharp corner serves as a focal point for strain and breakage is frequently found at these focal points. By undercutting the stud portion adjacent the threads to an amount slightly in excess of the thread depth, a concentration of forces is avoided at the point where the thread and the thread undercut come together. By this means, breakage of the stud in the area near the threads is minimized. This area has been a frequent point of breakage in prior assemblies.

Broadly speaking, the tensioning stud is a resonating system and the rest of the transducer assembly is a force generating assembly which is designed to oscillate at the same frequency as the tensioning stud.

The force generating assembly 1 of the transducer 30 shown in FIG. 1 has annular elements 2, 3 made of a ceramic or any other commonly used piezoelectric or polarized electrostrictive material. Located centrally of the two annular electrostrictive elements is a flat electrically conductive disk 4 having a hole 5 through its center. The disk is positioned between the annular electrostrictive elements 2, 3 and in intimate contact with them along its sides 6, 7. Adjacent each electrostrictive element on its outside are flat annular disks 8, 9 made of steel or the like. Each flat annular disk is preferably made of the same material as are the tapered tubular means or sleeve means 10, 11 which lie just outside of it. The sleeve is taken as including the flat annular disk. Tensioning stud 12 runs through the entire assembly. The stud may have an irregular cross-section, such as a hexagonal cross-section. The flat annular disk is made to fit snugly about the stud. The hexagonal cross-section of the hole 13 in the disc prevents relative turning between the stud 12 and disk 8, 9. Both sides 14, 15 of each flat annular disk are smooth so that on one side there is a close contact with each annular electrostrictive element 2, 3 and on the other side, there is a close contact with the flat end 16, 17 of the sleeve means. The sleeve means has a flat end 16, 17 which is shown in contact with the annular disks 8, 9 and at the other end, it has internal threads 18 for matching with the threads 19 of the tensioning stud 12. A tubular spacer 20 made of an electrically nonconducting material such as nylon is placed in the space between the annular electrostrictive elements 8, 9 and the outer part of the tensioning stud 12. Tubular spacer 20 extends from one flat annular disk 8 to the other 9. Centering rings 21, 22 made of a resilient metal fit into grooves 23, 24 in the flat annular disk and also fit into another set of grooves 25, 26 in the inner edge of the tubular means as shown in FIG. 1. Each centering ring fits snugly into the grooves and extends completely around the interior of the flat annular disk and the sleeve means.

The tensioning stud has at least one flat portion 27 on its exterior to match with a flat portion of the interior of each of the flat annular disks. The matching flat portions prevent relative turning of these elements. In practice, the stud is made hexagonal and the interior of the flat annular disks 8, 9 is made hexagonal. The pur-

pose of the matching hexagonal parts of the stud and the flat annular disk is so that the sleeve means may be turned independently of the stud 12, flat annular disks 8, 9 and annular electrostrictive elements 2, 3. In practice, one of the sleeve means is screwed onto a stud until its threaded end is about flush with the stud end. The stud is recessed a bit to allow later torquing of the horn up against the sleeve. A set screw 28 in the side of the sleeve means is tightened and the sleeve means and stud are fixed in position relative to each other. Next the transducer is assembled as shown in FIG. 1 and the second sleeve means is rotated until it puts the electrostrictive elements into the requisite compression. As the transducer elements approach each other, the centering rings 21, 22 center the flat annular disks and the force transmitting sleeve means relative to each other because each centering ring 21, 22 falls into the grooves 23-26 in the disk and tapered tubular means. The flat annular disk is held from turning by the hexagonal stud. The disk may slide longitudinally on the stud. The tapered sleeve means is turned until the desired tension and compression is put upon the resonating structure and the force generating assembly respectively.

The relative dimensions of the force transmitting sleeve 10, 11, the flat annular disks 8, 9 and the annular electrostrictive elements 2, 3 are of considerable consequence for the following reasons. If stud dimensions deviate substantially from a half wave length, considerable stress must be applied to the end of the stud to force oscillation of the stud. If such a stud is used as a preloading stud, the nominal dynamic stress in the threaded portions 19 at its ends will be undesirably high. On the other hand, if the tensioning stud is made approximately one half wave length long, then a way must be found to make the body of the transducer to resonate at the same length and frequency. If these two bodies, both being one half wave length long, resonate at the same length and the same frequency, there is a minimum of dynamic stress at the ends of the stud. This is because each end of the tensioning stud is in phase with the corresponding end of the force generating assembly.

The resonant length of most conventionally designed transducers is considerably less than a half wave length. These transducers use steel, stainless steel, titanium, or other suitable stud materials. The reason is that the elastic modulus of the ceramic electrostrictive element is substantially lower than that of the metallic elements which make up the rest of the transducer. Furthermore, in most conventional designs, the cross-sectional area of the electrostrictive element (area of the ceramic material) is smaller than the cross-sectional area of the end sleeves. This brings about a situation in which the transmitter body may be considered as a bar with a short zone at midlength which is very low in stiffness.

In the present invention, the zone of the electrostrictive element is made as stiff as the remainder of the transducer body by proportioning the cross-sectional areas of the tubular means 10, 11 and the annular electrostrictive element 8, 9 inversely as their moduli of elasticity, so that

$$\text{Area}_{ee} \times E_{ee} = \text{Area}_{SM} \times E_{SM}$$

where

Area_{ee} = area of the annular electrostrictive element taken across its axis,

E_{ee} = modulus of elasticity of the electrostrictive element.

Area_{SM} = the cross-sectional area of the sleeve means taken along a line perpendicular to its direction of vibration.

and,

E_{SM} = the modulus of elasticity of the sleeve means.

When the conditions above are met, the length of both the stud 12 and the force generating assembly 1 shown in FIGS. 1 and 3 may be constructed very close to one half wave length and the distance from the flat electrically conductive disk 4 to each end of the transducer may be constructed very close to one quarter wave length. Within the scope of this invention, a variety of materials may be used.

Because of the presence of the changes of area of the cross-section along the length of the stud, the resonant length of the stud will not be quite the same as for a resonant bar of uniform cross-section even though the average cross-sectional area is identical. As one method of construction, the force generating assembly can be made to resonate at about the same length as the stud by turning the end sleeves down on a lathe to achieve an appropriate cross-sectional area so that the stud and force generating assembly resonate in phase. As a matter of practice, the amount of sleeve material that must be machined off is small.

Since the force generating system 1 is matched with the resonant oscillating stud 12 as to acoustic length, an end of this system may be used for transmitting energy to a horn. Such a device 29 is shown assembled in FIG. 2. The center zone of the transducer assembly 30, i.e. the electrostrictive element 2, 3, is longer than in conventional transducers and stud 12 and force generating system 1 are perfectly matched as to acoustical length. The total length of the transducer assembly 30 is greater than in a conventional transducer. The additional transducer length allows a greater displacement of each end of the transducer assembly. There is induced a larger oscillation amplitude at the same maximum stress in consequence of the greater length of the transducer assembly. It can be shown theoretically that of two transducers operating at the same resonant frequency, the one having the longer sleeves exhibits the larger displacement amplitude.

The horn 31 shown in FIG. 2 has a transducer 30 of my invention attached to it. The transducer 30 is threaded onto the stud 32 and fits snugly against the horn 31. The transducer assembly and horn are a total of one wave length from the tip of the blade to the distal end of the transducer. The distance from the tip 32 of the horn blade 33 to the point 35 of attachment is about one-quarter wave length of the horn to the base assembly. The distance from the point 35 to the point of attachment 34 between the horn and the transducer is about one-quarter wave length. As indicated above in the preceding paragraphs, the distance between the force transmitting end 36 of the transducer and the flat electrically conductive disk 4 is about one-quarter wave length and from the flat electrically conductive disk 4 to the distal end 37 of the transducer assembly is likewise about one-quarter wave length. Thus, it is readily apparent that the length of the transducer assembly 30 plus the horn 31 is one full wave length. When the transducer assembly and horn are supported in this fashion, the points of maximum displacement of the transducer assembly are at the ends 36, 37 of the

transducer and at the end 32 of blade 33 of the horn. The horn is hung or supported by the flanged portion 38 at its midpoint, this being a point of maximum stress and minimum displacement.

The end view of my transducer taken along the line 3—3 of FIG. 2 has a cut-away section. The stud 12 shown in FIGS. 1 and 3 is hexagonal in its center section 39 and is shown in FIG. 3 as matching with the interior hexagonal shape of the hole 13 through the flat annular disks. The lower portion of the end view of FIG. 3 shows the lower part of the end view of the transducer. The end of stud 12 is shown as rounded and the hexagonal cross-section 40 of the outer tubular element 10, 11 is shown. Concentric with the flat annular disks 8, 9 and extending exterior to the disk flat to the tubular section is the insulating annulus 20 (not shown in FIG. 3). The electrically conductive disk 4 is shown extending beyond annulus 20. The only real criterion for the electrically conductive disk is that it be located between the annular electrostrictive elements 2, 3 so that the potential applied to disk 4 is applied laterally equally to each of the elements 2, 3 in order that electrical energy is delivered equally to the elements. For this reason, even though an annular electrically conducting disk is shown extending well beyond the annular electrostrictive elements 2, 3, it is necessary only that the disk extend outwardly to such an extent that an electrical attachment may be made to it so as to bring electric potential across the electrostrictive elements. Annular disk 4 is shown as large and may be used to radiate heat or to be a radiating and cooling surface since considerable heat may be generated by the annular electrostrictive elements.

Some of the advantages of my device are that a larger oscillation amplitude displacement is possible because with a longer transducer, the displacement at the ends of the transducer assembly is greater. Another advantage is that because of the correspondence of resonance between the tension stud and the force generating system, cracking of the stud or transducer assembly near the ends of the transducer assembly structure is reduced to a minimum. Cracks appear mostly because of localized stresses brought about by forced stud displacement and high dynamic stress. These cracks cause early failure of the assembly because the phase displacement of the ends of the transducer assembly is the same in both the stud and force generating assembly. Undercutting at the ends of the stud provides a means for avoiding localization of any stress which may be applied at the ends of the stud and transducer assembly.

The foregoing is a description of an illustrative embodiment of the invention and it is applicant's invention in the appended claims to cover all forms which fall within the scope of the invention.

What is claimed is:

1. A transducer assembly comprising:
 - a force generating assembly comprising;
 - a first tubular means including a sleeve means at a first end and having an internal threaded portion at said first end and a flat portion at a second end;
 - a first annular electrostrictive element mounted adjacent said flat portion of said first tubular means and having an outside diameter about equal to the outside diameter of said first tubular means and an inside diameter greater than the least internal diameter of said first tubular means, dimensioned so that the cross-sectional area of said element multiplied

by the modulus of elasticity of the element about equals the cross-sectional area of said sleeve means multiplied by the modulus of elasticity of said sleeve means;

- a flat electrically conductive disk having an outside diameter greater than that of said electrostrictive element and an inside diameter about that of the inside diameter of said electrostrictive element;
 - a second annular electrostrictive element mounted adjacent said flat electrically conductive disk and constructed nearly identical to said first annular electrostrictive element, and
 - a second tubular means including a sleeve means at a first end and having an internal threaded portion at said first end and a flat portion at a second end adjacent said second electrostrictive element, dimensioned so that the cross-sectional area of said element multiplied by the modulus of elasticity of the element about equals the cross-sectional area of said sleeve means multiplied by the modulus of elasticity of said sleeve means; and
 - a tensioning stud of about the same material and cross-sectional area as said first and second tubular means and having a first threaded end and a second threaded end and fitting through said first and second force transmitting sleeve, said first and second electrostrictive elements and said flat electrically conductive disk with its first end threaded into said first end of said first sleeve and its second end threaded into said second end of said second sleeve whereby said first and second tubular means, said first and second annular spacer, said first and second electrostrictive element and said conductive disk are pressed against each other and placed in compressive strain whereby the resonant frequencies, phases and amplitudes of the stud and force generating assemblies are matched.
2. A transducer assembly as set forth in claim 1 in which each said first means comprises;
 - a tapered sleeve means having an internal threaded portion at a first end and a flat portion at a second end; and
 - a flat annular disk mounted adjacent each said second end of said tapered tubular means whereby one side of said annular disk is in contact with said flat portion of said second end
 - a flat annular disk mounted adjacent each said second end of said tapered tubular means whereby one side of said annular disk is in contact with said flat portion of second end.
 3. A transducer assembly as set forth in claim 2 further comprising;
 - a tubular spacer made of an electrically insulating material and mounted about said stud and between said stud and the inside of said annular electrostrictive element whereby said electrostrictive elements are electrically insulated from said tensioning stud.
 4. A transducer assembly as set forth in claim 2 further comprising;
 - a first groove extending completely around an inner shoulder of said flat annular disk;
 - a second groove extending around the inner shoulder of said flat section of said tapered sleeve means and of the same external diameter as said groove in said flat annular disk; and
 - a centering ring of size to fit snugly into said first and second groove whereby said flat annular disk and

said tubular means may be turned relative to each other without changing the lateral distance between the tensioning stud and the tubular sleeve.

5. A transducer assembly as set forth in claim 2 in which said tensioning stud comprises;
an elongated stud the cross-section of which has at least one flat portion.

6. A transducer assembly as set forth in claim 5 in which each of said first and second annular disks comprises;

a flat disk having a circular exterior with at least one flat portion on its inner circumference to match with said flat portion on said elongated stud.

7. A transducer assembly as set forth in claim 6 in which each said tensioning stud and annular disk comprise;

at least six flat matching portions on each said tensioning stud and annular disk.

8. A transducer assembly as set forth in claim 6 in which said threads on said first and second end of said tensioning stud further comprise;

threads cut in one direction on said stud whereby when said first and second tapered tubular means are rotated in the same direction about said stud said tubular means turn against said flat annular disk and said first and second tapered tubular means are moved toward each other to finally place said tensioning stud in tension and said first and second sleeve, said first and second electrostrictive elements and said conductive disk in compressive strain.

9. A transducer assembly as set forth in claim 2 in which;

the distance from said conductive disk to said threaded end of said first tubular sleeve means is the same as the distance from said conductive disk to said threaded end of said second tubular sleeve means.

10. An ultrasonic welding apparatus comprising in combination;

a transducer having a first force transmitting sleeve means having a first flat end and a second internally thread end,

a first annular electrostrictive element mounted adjacent said first sleeve means, and having an outside diameter about equal to the outside diameter of said first sleeve means and an inside diameter greater than the least internal diameter of said first sleeve means, whereby the cross-sectional area of said element multiplied by the modulus of elasticity of the element about equals the cross-sectional area of said sleeve means multiplied by the modulus of elasticity of said sleeve means,

a flat electrically conductive disk having an outside diameter greater than that of said electrostrictive element and an inside diameter equal to that of the inside diameter of said electrostrictive element,

a second annular electrostrictive element mounted adjacent said flat disk and having the same dimensions as said first annular electrostatic element,

a second force transmitting sleeve means having a

first flat end and a second end with internal threads,

a tensioning stud having a first threaded end and a second threaded end and fitting through said first and second force transmitting sleeve, said first and second electrostrictive elements and said flat electrically conductive disk with its first and its second end threaded into said second end of said second sleeve whereby said first and second tubular sleeve, said first and second annular spacer, said first and second electrostrictive element and said conductive disk are pressed against each other and placed in compressive strain,

a horn having,

a head adapted to be attached to said first end of said tensioning stud end of a length equal to half the length of said transducer,

a flange attached to said head at its most remote point from said tensioning stud and adapted to be attached to a first point, and

a stem attached to said head at a point remote from said tensioning stud whereby power generated in said transducer may be applied to an object through said strain.

11. An ultrasonic transducer assembly comprising, in combination:

a tubular force-generating component of sandwich construction and including electrostrictive means located in the central region along the axis of said tubular force-generating component and a pair of sleeve members forming the opposite ends of said tubular force-generating component whereby maximum axial vibrational displacement of selected frequency is effected at the free ends of said sleeve member in response to excitation of said electrostrictive means, said free ends of the sleeve members being internally threaded; and

a stud disposed coaxially within and essentially coextensive in length with said tubular force-generating component, said stud being threadedly engaged at its opposite ends to the respective free ends of said sleeve members and being pretensioned to place said tubular force-generating component in compression;

the cross-sectional dimensions of said tubular force-generating component and of said stud being cooperatively related to produce vibrational displacements of the respective threadedly joined portions of said stud and of said force-generating component which are substantially in phase at said selected frequency and of substantially equal amplitudes whereby minimally to stress such threadedly joined portions.

12. An ultrasonic transducer assembly as defined in claim 11 wherein the product of the modulus of elasticity of said electrostrictive means and its cross-sectional area is substantially equal to the product of the modulus of elasticity and the cross-sectional area of each sleeve member.

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