

Aug. 2, 1960

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2,947,886

PIEZOELECTRIC ULTRASONIC TRANSDUCER

Filed April 29, 1958

2 Sheets-Sheet 1

Fig. 1.

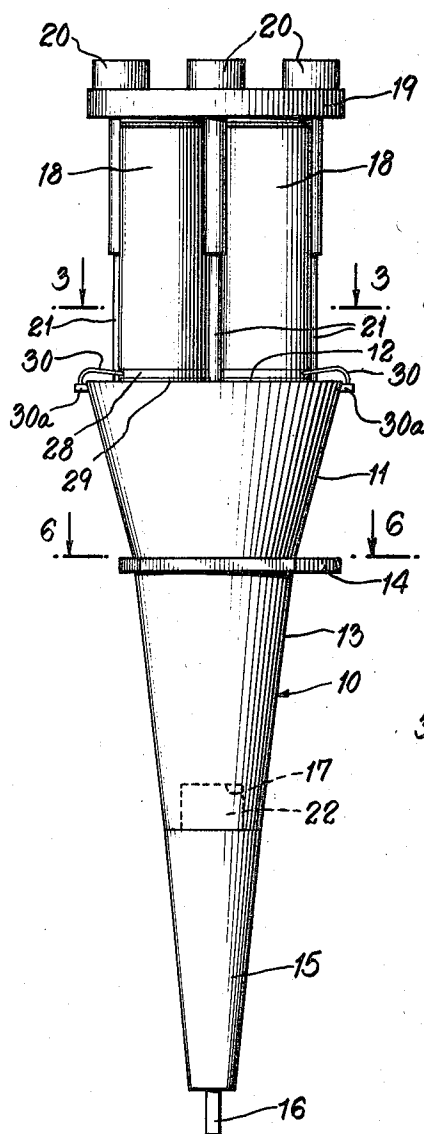


Fig. 2.

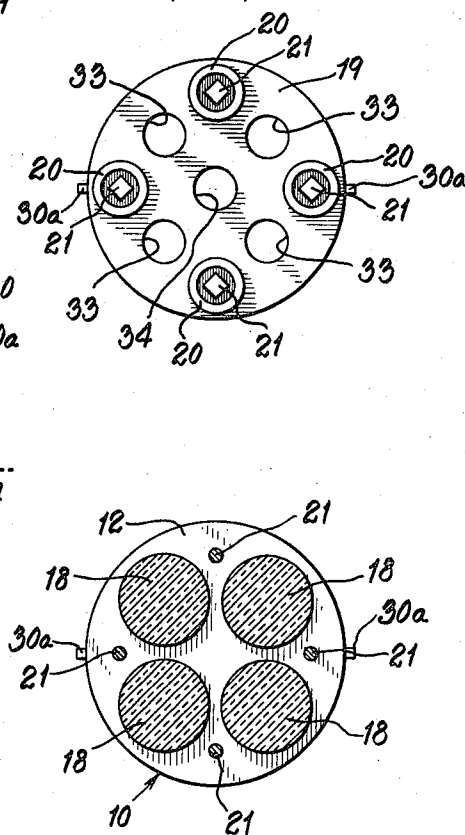


Fig. 3.

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2 Sheets-Sheet 2

Fig. 4.

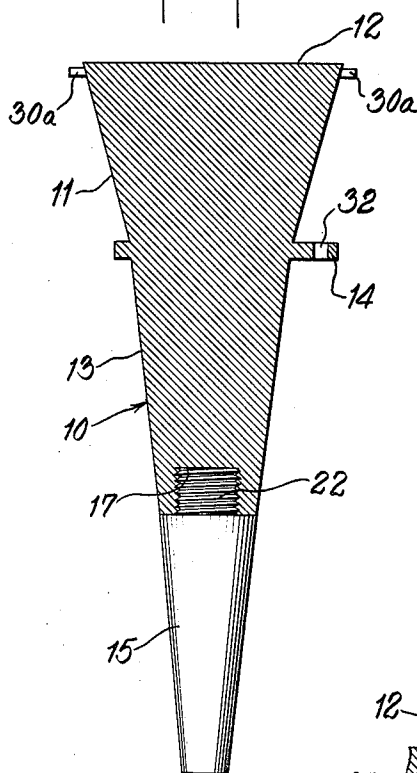


Fig. 5.

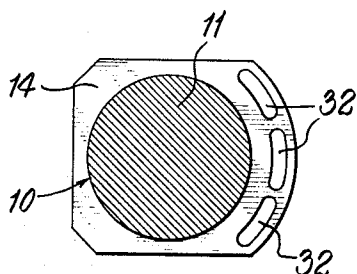
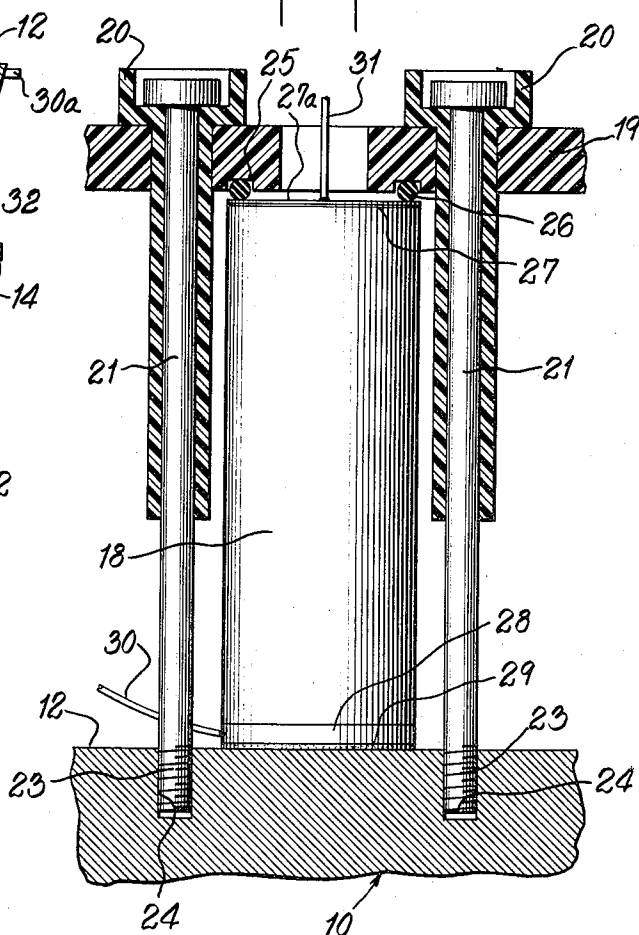


Fig. 6.

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1

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PIEZOELECTRIC ULTRASONIC TRANSDUCER

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8 Claims. (Cl. 310-8.3)

My invention relates to ultrasonic devices and mechanical transformers therefor and in particular to those which may be utilized in ultrasonic drills, welders and like devices.

It is an important object of my invention to provide a mechanical transformer for an ultrasonic device wherein there is high efficiency transfer of energy.

It is a further object of my invention to provide such a mechanical transformer which is conical in shape and is provided with a plurality of tapered sections whereby the cross section varies approximately exponentially.

It is a still further object of my invention to provide such a mechanical transformer which may be driven by a plurality of electromechanically sensitive bodies.

Other objects, features and advantages of my invention will be apparent during the course of the following description when taken in conjunction with the accompanying drawings wherein:

Figure 1 is an elevational view of a preferred embodiment of my invention,

Figure 2 is a top plan view of the embodiment of Figure 1,

Figure 3 is a cross-sectional view along the line 3-3 of Figure 1, viewed in the direction of the arrows,

Figure 4 is a view similar to Figure 1 showing the upper portion of the mechanical transformer in cross-section and the lower portion in elevation,

Figure 5 is an elevational view, partly in cross-section, showing the method of placing the electromechanically sensitive bodies under compression, and

Figure 6 is a cross-sectional view along the line 6-6 of Figure 1.

In the drawings, wherein, for the purpose of illustration, is shown a preferred embodiment of my invention, the numeral 10 designates the mechanical transformer, generally. Mechanical transformer 10 is comprised of three sections, denominated 11, 13 and 15, and mounting flange 14. The larger base of mechanical transformer 10 is designated 12. In its preferred form, I choose to fashion sections 11 and 13 and mounting flange 14 from a single piece of stock such as aluminum or like material. However, these elements may also be made in separate pieces and suitably bonded together. Flange 14 is located at a velocity node so that the assembly may be supported properly without coupling off any energy or lowering the Q of mechanical transformer 10. At the velocity nodes, the slope of the lines which generate the surfaces of the tapered sections changes. The slope of the line which generates the surface of section 11 has the smallest value, that of the line which generates the surface of section 13 has a slightly larger value, and that of the line which generates the surface of section 15 has a slightly larger value. The slopes are so chosen that, taken together, the surface of mechanical transformer 10 approximates that of a surface of revolution which has been generated by an exponential curve.

I choose to fashion section 15 from steel and to attach

2

it to section 13 by means of threaded element 22 which is formed from the same piece of stock as section 15. Threaded element 22 is threaded into threaded opening 17 which is carried by section 13. Tool end 16 is suitably attached to the small end of section 15, by means of matching threads on tool end 16 and in the small end of section 15 or by a set screw or similar means (attaching means not shown). In the form of my invention shown in the figures, I prefer to fashion section 15 from stainless steel but other similar materials may also be used. Sections 11, 12 and 13 may, if desired, be formed from a unitary piece of stock. The acoustical continuity, when section is threaded into the balance of mechanical transformer 10 and is so machined as to bottom mechanically in hole 17, is preserved by filling any gaps, especially at the shoulder, with epoxy resin. The epoxy resin generally comprises a base resin combined with a hardener such as, for example, metaphenylene diamine, and inert mineral fillers. Consistency can be controlled by the addition of diluents in a manner well-known in the art such as has been described in the article entitled "Where and How to Use Epoxies" by Jerome Formo and Luther Bolstad on pages 99 and 104 of Modern Plastics, July 1955, volume 32, No. 11.

Electromechanically sensitive bodies 18 are preferably formed of piezoelectric ceramic consisting largely of barium titanate but other piezoelectric ceramics, ferroelectric ceramics or electromechanically sensitive materials may be used with equally efficacious results. Such other materials include, among others, the natural piezoelectrics and the magnetostrictives. Bodies 18 are solid cylinders, in the embodiment illustrated, and have applied to their end surfaces, by painting, evaporating, sputtering, or any other method well-known in the art, metallic electrodes 27 and 28 of silver or similar material. Electrical leads 30 are suitably attached by soldering or otherwise to electrode 28 and electrical leads 31 are suitably attached through shim 27a to electrode 27. Leads 30 are connected to ground lugs 30a and leads 31 are connected to the high side of the ultrasonic generator (not shown). Shims 27a are preferably formed from brass foil sheets about 5 mils thick which are pressed into intimate contact against electrodes 27 by means of O-rings 26. Shims 27a are pretinned so that leads 31 can be soldered thereto. Leads 31 are carried away from the assembly through holes 33 in plate 19.

Hole 34 is provided in plate 19 to receive an adapter from an air supply (not shown) in order to admit cooling air into the space between the four bodies 18. These spaces are made large enough to provide for elimination of the exhaust air around each body 18.

Bodies 18 are affixed to mechanical transformer 10 by means of an epoxy resin 29, such as has been described above. The epoxy is baked for four hours at 150° F. which temperature is below the transformation temperature of bodies 18. The time and temperature are interdependent and the time may be shortened if the temperature may be raised depending on the ceramic transformation temperature. On the other hand, if the temperature must be lowered, the time must be increased. The epoxy may also be cured at room temperature, if desired, in which case the time must be increased considerably.

Plate 19 is rigid and is formed of a plastic molded on layers of linen cloth for strength but may also be formed of other rigid plastics or conductive metals such as steel, brass and similar materials. Plate 19 has cut therein grooves 25 which are of approximately the same radial dimensions as the various bases of the several electromechanically sensitive bodies 18 and of approximately $\frac{1}{20}$ the area of the surface of the base of each

body 18. O-rings 26, which fit in grooves 25, are of the same shape as the grooves and are formed of neoprene rubber or similar resilient material. Holes are provided in plate 19 to receive bolts 21 which are threaded at the ends as at 23 so as to mate with threaded holes 24 which are carried in base 12 of mechanical transformer 10. Insulator 20 is formed of Teflon or similar material and is employed to insulate plate 19 from bolts 21 and mechanical transformer 10.

Mounting flange 14 is provided with holes 32 into which mounting bolts or similar elements (not shown) may be inserted in order to support the completed assembly.

The units of my invention are assembled in the following manner:

Bodies 18 are coupled to base 12 by means of a somewhat rigid type of epoxy resin such as has been described heretofore. Then the bodies 18 are clamped against base 12 to attain good mechanical strength in the assembly. This is accomplished by means of plate 19 which carries grooves 25 into which O-rings 26 are fitted and holes through which bolts 21 are fed. The bolts 21 are coated with the epoxy resin heretofore described at 23 and are threaded into holes 24. Then all four bolts are torqued down evenly so as to equalize pressure on all four bodies 18. After adjustment, the entire assembly is baked in order to harden the epoxy resin and maintain permanent adjustment of the unit.

Since the activity of mechanical transformer 10 depends to a large extent on the clamping pressure on the bodies 10, the relative activity is measured during assembly of the unit by the usual resonance techniques (voltage vs. frequency, etc.). I have found that up to a certain value of torque on bolts 21, as for example, 7½ inch-pounds on ¼ inch studs, there is little change in electrical activity. However, when the units are used, thermal expansion and the high accelerations to which some of the parts are subjected cause some change in the pressure on bolts 21. Since I desire to achieve the highest compressional bias consistent with usable activity, I have found that it is best to adjust the torque to the highest limit at which initial activity is slightly reduced. Then, after a few minutes of use under excitation from the ultrasonic generator (not shown), the pressure level shifts resulting in a maximum compressional bias with minimum damping effect.

It should be noted that all surfaces to which epoxy resin is applied are sandblasted and intensively cleaned in order to guarantee that solid bonds will be maintained despite the high acceleration to which the combination is subjected.

By way of illustration and not by way of limitation of the scope of my invention, following is an example of a mechanical transformer driven by four electromechanically sensitive bodies:

Mechanical transformer 10 is a full wavelength long at 20 kc. The base 12 is 4" in diameter. Each body 18 is 1½" in diameter and 4¼" long. Bodies 18 are driven in length mode and have an unloaded resonant frequency of 20 kc. The entire assembly, including the tool end 16 and the electromechanically sensitive bodies, is 14¾" long, resonates at 19 kc. and is one and a half wavelengths at 19 kc. The diameter of base 12 is nearly in half wave radial resonance at this frequency but the much higher Q in the length mode reduces degenerate cross coupling at this point. The combination has a displacement gain of about 50 and an electrical input Q of 140.

It is within the contemplation of my invention to utilize a single electromechanically sensitive body in place of the four shown and described or to use any other number of such bodies. It is also within the scope of my invention to operate ultrasonic devices such as I have described at other frequencies than that set forth in the example above.

It is consistent with and within the contemplation of my invention to use a rigid plate which is larger in diameter than the large base of the mechanical transformer and the holes for the clamping bolts are located so that the bolts clear the mechanical transducer base and are threaded into or similarly affixed to the mounting flange. This method of clamping, since it is accomplished at a nodal surface, results in no vibration in the bolts, insulators, and the rigid plate.

Furthermore, the number of tapered sections making up the mechanical transformer may be more or less than the three illustrated and shown. As the number of tapered sections is increased, the overall surface configuration approaches one generated by an exponential curve.

While I have described my invention by means of specific examples and in a specific embodiment, I do not wish to be limited thereto, for obvious modifications will occur to those skilled in the art without departing from the spirit and scope of the invention.

Having thus described my invention, I claim:

1. An ultrasonic device comprising a tapered mechanical transformer substantially conical in shape, a plurality of electromechanically sensitive bodies affixed to the larger base of said mechanical transformer, a rigid plate carrying grooves therein, said mechanical transformer comprising first, second and third tapered sections, said first tapered section being adjacent the base with the largest area, said second tapered section having its larger base adjacent the smaller base of said first tapered section, said third tapered section having its larger base adjacent the smaller base of said second tapered section, the line generating the surface of said first tapered section having the smallest slope, the line generating the surface of said second tapered section having a greater slope than that generating the surface of said first tapered section, the line generating the surface of said third tapered section having a greater slope than that generating the surface of said second tapered section, the transitions from one said tapered section to the next adjacent tapered section being at a velocity node of said mechanical transformer, said rigid plate being at the ends of said electromechanically sensitive bodies opposite the ends affixed to said mechanical transformer, each of said grooves being of approximately the same dimension as the perimeter of the surface of the electromechanically sensitive body to be clamped and whose area is less than approximately ½ the area of said surface, a resilient member within said groove and in contact with said electromechanically sensitive body, acoustic transmission means in contact with each said electromechanically sensitive body and the larger base of said mechanical transformer, means for applying compression between said rigid plate and said mechanical transformer, and means for insulating said rigid plate from said mechanical transformer.

2. An ultrasonic device as described in claim 1 including means for supplying excitation to said electromechanically sensitive bodies.

3. An ultrasonic device as described in claim 1 wherein said electromechanically sensitive bodies are composed largely of piezoelectric ceramic.

4. An ultrasonic device as described in claim 1 wherein said means for applying compression between said rigid plate and said mechanical transformer comprises a plurality of bolts running between said rigid plate and a mounting flange, said mounting flange being at the transition from said first tapered section to said second tapered section.

5. An ultrasonic device comprising a tapered mechanical transformer substantially conical in shape, at least one electromechanically sensitive body affixed to the larger base of said mechanical transformer, a rigid plate carrying grooves therein, said mechanical transformer comprising first, second and third tapered sections, said first tapered section being adjacent the base with the

5

largest area, said second tapered section having its larger base adjacent the smaller base of said first tapered section, said third tapered section having its larger base adjacent the smaller base of said second tapered section, the line generating the surface of said first tapered section having the smallest slope, the line generating the surface of said second tapered section having a greater slope than that generating the slope of said first tapered section, the line generating the surface of said third tapered section having a greater slope than that generating the surface of said second tapered section, the transitions from one said tapered section to the next adjacent tapered section being at a velocity node of said mechanical transformer, said rigid plate being at the end of said electromechanically sensitive body opposite the end affixed to said mechanical transformer, said groove being of approximately the same dimension as the perimeter of the surface of said electromechanically sensitive body and whose area is less than approximately $\frac{1}{20}$ the area of said surface, a resilient member within said groove and in contact with said electromechanically sensitive body, acoustic transmission means in contact with said electromechanically sensitive body and the larger base of said mechanical transformer, means for applying compression between said rigid plate and said mechanical transformer, and

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means for insulating said rigid plate from said mechanical transformer.

6. An ultrasonic device as described in claim 5 wherein said electromechanically sensitive body is composed largely of piezoelectric ceramic.

7. An ultrasonic device as described in claim 5 including means for supplying excitation to said electromechanically sensitive body.

8. An ultrasonic device as described in claim 5 wherein said means for applying compression between said rigid plate and said mechanical transformer comprises a plurality of bolts running between said rigid plate and a mounting flange, said mounting flange being at the transition from said first tapered section to said second tapered section.

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