

June 15, 1971

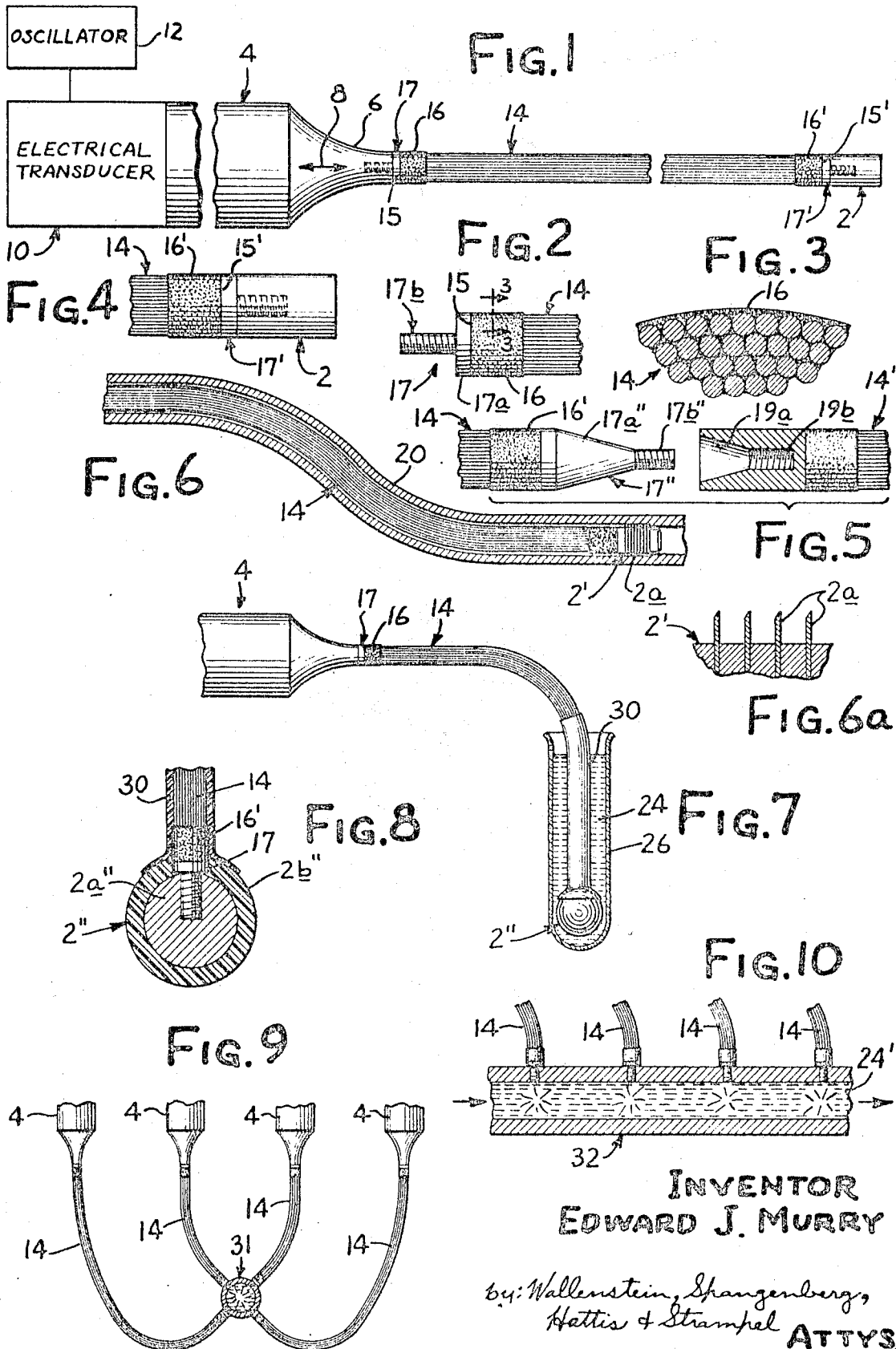
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3,584,327

SUBSTITUTE FOR MISSING XR
Filed April 4, 1969

ULTRASONIC TRANSMISSION SYSTEM

2 Sheets-Sheet 1



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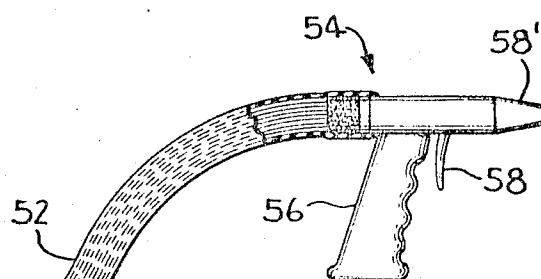
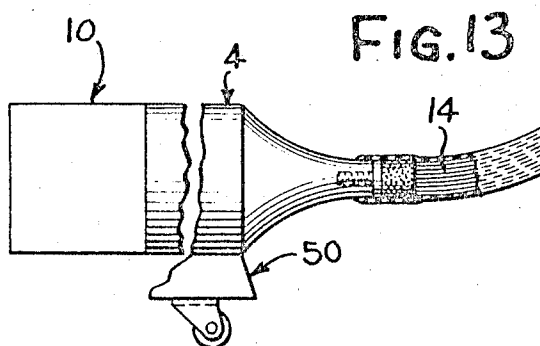
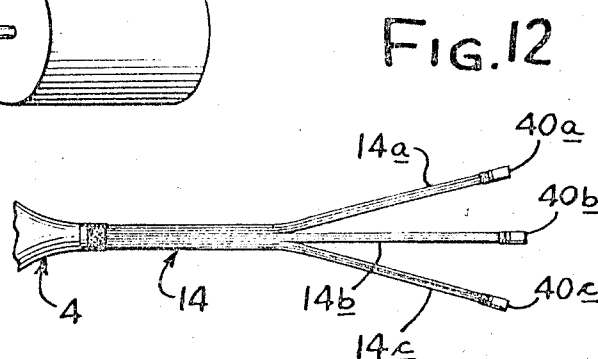
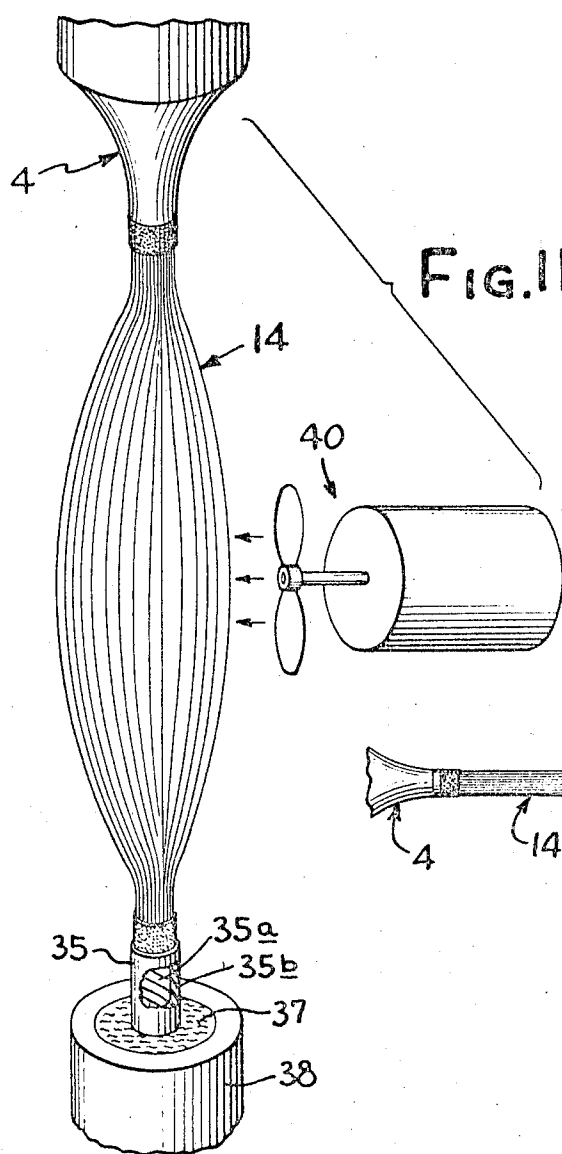
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2 Sheets-Sheet 2



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ULTRASONIC TRANSMISSION SYSTEM

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23 Claims

ABSTRACT OF THE DISCLOSURE

A source of longitudinal vibrations is transmitted to a utilization device to be vibrated and positioned in substantial spaced apart relation from a source of vibrations by a unique vibration transmission system which can concentrate an extremely large amount of energy in a very small space. The transmission system comprises a flexible bundle of as many as 100 or more fine wires connected at one end to the source of vibration and at the other end to the utilization device so longitudinal waves are propagated separately along each of the wires. The wires are surrounded most advantageously by an air medium. The acoustic impedance of the material out of which the wires are made is most advantageously selected at least roughly to match that of the utilization device.

This invention relates to the transmission of vibration energy to various utilization devices, such as ultrasonically driven tools. Ultrasonic energy is becoming increasingly popular as a means for driving welding, scale removing, agitating, cleaning and drilling devices. In such case, the utilization devices or tools to be vibrated are commonly secured rigidly and directly upon the end of a sonic transformer vibrated by a transducer unit which generally converts high frequency electrical energy to mechanical vibrations. The assembly of the transducer unit, sonic transformer and utilization device generally comprise a relatively bulky assembly, particularly where the vibration energy levels involved are in the order of 1-10 watts per square centimeter and higher. Accordingly, it has not been heretofore practically possible to utilize ultrasonic vibration energy at power levels where such energy must be delivered to remotely located areas or to tiny or inaccessible areas such as small conduits and orifices, or where there are explosive atmospheres where electrical wiring, which could cause sparking, is prohibited, or to environments of very high temperatures (like 300-1000° F.) which would adversely affect the transducer.

It is, accordingly, an object of the invention to provide a unique vibration transmission means for transmitting vibrations at high power levels and at high efficiency between a source of vibrations, such as an electrical transducer and attached sonic transformer, and a utilization device to be vibrated located at a remote or normally inaccessible point, which may be in an explosive atmosphere, or which can only accommodate a utilization device of a very small size, such as a small orifice or conduit, or which may be in a high temperature environment which may damage the transducer or its electrical leads.

Another object of the invention is to provide a vibration transmission means as described, which occupies a very small cross-sectional area and which is flexible so that it may be inserted and pushed through small conduits and the like traversing non-linear paths. A further object of the invention is to provide a sonic vibration transmission means as described which is easy to install in existing processing systems.

In accordance with the present invention, it has been discovered that a bundle of flexible wires comprising, for example, at least several dozens of wires, most advantageously a hundred or more wires, each of extremely small cross-sectional areas, form a very efficient transmitter of longitudinal vibrations when fixedly secured at its opposite ends between a source of vibrations such as a sonic transformer and a utilization device which most advantageously has an acoustic impedance which at least roughly matches that of the wires. For example, it was discovered that a bundle of wires made of steel, glass or the like, each only 0.002 inches in diameter and occupying an overall cross-sectional area of only 4 square millimeters can very efficiently carry vibrational acoustic energy at power levels of as much as 100 watts per square centimeter. A bundle of such wires is exceedingly flexible, and one would not expect that such a flexible bundle of wires would efficiently transmit mechanical vibrations. The wires should be in a medium such as air or other media which has acoustic impedances many orders different from that of the wires.

It is significant to note that the replacement of the bundle of wires by a single rod of the same size or mass would result in such large compressional and tensile forces within the rod, at 100 watts per square centimeter, that it would probably fracture under the work load, thus placing a severe limit on the usable energy extraction. However, the use of a hundred or more very thin, extremely high strength wires in a bundle permit much greater input and extraction energies (10 to 100 times greater) and also provide the very important advantage of bendability, and the ability to use one or a number of separate wire bundles extending from a single generator to different points to be vibrated or to use several high power generators feeding through separate wire bundles into a single high energy utilization device. Although a group of a relatively small number of wires has been used in the prior art as individual utilization device, that is as the ultimate elements to be vibrated, in soldering applications and as a liquid vibrating means, a bundle comprising an extremely large number of very small wires has not been used as an efficient vibration transmitting means between a source of vibrations and a separate utilization device to be vibrated as described.

The above and other objects, advantages and features of the invention will become apparent by making reference to the specification to follow, the claims and drawings wherein:

FIG. 1 shows an ultrasonic tool including a liquid bundle of wires connecting a sonic transformer to a tool to be vibrated;

FIG. 2 is an enlarged fragmentary view of the inner end of the bundle of wires shown in FIG. 1 showing the means by which the bundle of wires is connected to the sonic transformer;

FIG. 3 is an enlarged fragmentary transverse sectional view of the inner end of the bundle of wires shown in FIG. 2, taken along section line 3-3 thereof;

FIG. 4 is an enlarged view of the outer end of the bundle of wires of FIG. 1 fitting into the utilization device;

FIG. 5 is an exploded view of the outer end of the bundle of wires of FIG. 1 with a modified connector attached to another similar bundle of wires to extend the overall length of the vibration transmission system;

FIG. 6 shows the bundle of wires of FIG. 1 attached to a reaming tool, the bundle of wires and reaming tool extending into a blood vessel;

FIG. 6a is an enlarged sectional view of the reaming tool shown in FIG. 6;

FIG. 7 shows another form of the invention where the bundle of wires and a tool to be vibrated extends into a liquid filled vessel;

FIG. 8 is a longitudinal sectional view through the tool at the end of the bundle of wires shown in FIG. 7;

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FIG. 9 shows a number of separate vibration generators connected to a common high energy utilization device by individual bundles of wires;

FIG. 10 is a view of a number of bundles of wires secured to a utilization device in the form of a wall of a conduit to be vibrated in an on-line emulsifier apparatus either from on or a plurality of generators;

FIG. 11 is a view showing a bundle of fan-cooled wires of FIG. 1 attached to a vibrating agitator head for agitating molten metal;

FIG. 12 shows a single source of vibrations split connected by small bundles of wires to different utilization devices; and

FIG. 13 is a view of a high power sonic vibratory tool assembly wherein the user manually carries and operates a vibrating tool unit connected through a flexible bundle of wires to a non-portable sonic motor.

Refer now to FIG. 1 which shows an ultrasonic tool assembly comprising a utilization device 2 to be vibrated longitudinally. The utilization device 2, for example, could be a tool to perform a metal cutting or fastening operation or an agitating device to agitate the wall of a conduit or container or to agitate a liquid directly. The utilization device 2 is shown positioned remotely from a source of vibrations illustrated as a sonic transformer 4 having a conventional tapered neck portion 6 which is vibrated along a longitudinal axis line 8 by an electrical transducer 10 driven by a suitable oscillator 12 in the conventional manner. In the prior art, the utilization device 2 is rigidly secured to the end of the sonic transformer 4.

In accordance with the invention, the source of vibrations is connected to a bundle of wires 14. The inner ends of the bundle of wires 14 are most advantageously formed into an integral body 16 (FIG. 3) having a flat coplanar end face 15 which can be conveniently secured to the vibrating face of a source of vibrations, as by silver soldering or brazing the same together. The end face 16 of the soldered or brazed end portion 16 of the bundle of wires is then connected to the sonic transformer in any suitable way, as by cementing, soldering, brazing or welding the end face 15 of the same either directly to the end face of the sonic transformer or preferably to the flat head portion 17a of a connector 17 having a threaded shank portion 17b (FIG. 2) threading into a tapered socket 18 in the sonic transformer 4. The longitudinal vibrations of the bundle of wires 14 in the direction of the length thereof. In a similar way, the outer ends of the bundle of wires 14 are most advantageously soldered or otherwise secured together to form an integral body 16' with a flat end face 15' which is then in turn bonded directly or preferably indirectly by a connector 17' to the utilization device 2. The connector 17' may be identical with the connector 17 and thus extend into a threaded socket 18' in the utilization device 2 (FIG. 5). The bundle of wires 14 between the ends thereof are most advantageously flexible so that they can be extended along an irregular path like that shown in FIG. 6.

The wires 14 may comprise any one of a number of materials such as metal or glass fibers which are good sonic wave transmitting materials. Crystalline materials and metals like cast iron or lead are unsuitable for this purpose since they are acoustic wave absorbing materials. Most steels, however, are excellent vibration transmitting material and may be used.

The wires 14 may have a wide range of diameters, depending upon the particular size and power requirement specifications involved. Wires as small as .002 inch and smaller have been found to be satisfactory. The diameter of the individual wires, in any event, should be much smaller than one quarter of a wavelength of the vibrations and the length to diameter ratio is most desirably placed at least about 100:1. The use of a large number of fine wires rather than a single rod to transmit vibrations at high power levels per unit area (a wire differing from a

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rod in that a rod has a length to diameter ratio of greater than about 2:1 and much less than about 25:1 whereas a wire has a length to diameter ratio of at least about 25:1) distributes energy in such a way that the individual wires carry only a small proportional part of the energy and will not readily fracture at a high power level per unit area, and the sonic wave energy transmitted is principally in the form of longitudinal waves rather than in undesired transverse waves which create shear forces of large magnitudes. To minimize transfer of energy to the surrounding medium the wires must be surrounded by a medium such as air having an acoustic impedance much different than the wire's acoustic impedance. For example, where the wires are surrounded by air, as little as 0.004% of the energy in the wire is transmitted into the air. If the surrounding medium were water, as much as 12% of the energy being transmitted in the wire could be lost to the surrounding medium. Steel having an acoustic impedance of 47.5×10^6 , whereas air has an acoustic impedance of 41.3 (a ratio of about 1 to 100,000).

So that the soldered end portions 16-16' of the bundle of wires do not act somewhat like a rod, the length to diameter ratio thereof should be kept less than about 2:1 and preferably no greater than about 1:1 and it should also be made much less than a quarter wavelength long when operating at very high power levels.

Refer now to FIGS. 4 and 5 which illustrate an aspect of the invention wherein a modified male connector 17'' is provided which is adapted selectively to fit within a utilization device (not shown) having a socket designed to receive the modified male connector 17'' or, as illustrated, to fit within a female connector 19 attached to a second bundle of wires 14' extending the overall length of the wires interconnecting the sonic transformer 4 with a utilization device attached to the end of the various bundles of wires involved. The male connector 17'' has a tapered head portion 17a'' bonded to the brazed or soldered outer end portion 16' of the bundle of wires 14, and a threaded shank portion 17b'. The tapered head and threaded shank portions 17a'' and 17b'' of the male connector 17'' fit into correspondingly shaped socket portions 19a and 19b in the female connector 19.

FIG. 6 illustrates an embodiment of the invention wherein the bundle of wires 14 in FIG. 1 is attached to a utilization device 2' adapted to ream a conduit 20 following an irregular or curved path along which the flexible bundle of wires 14 with the utilization device 2' attached must be extended to ream out the entire length of the conduit 20. The utilization device 2' thus forms a reaming tool having axially spaced reaming projections or edges 2a (FIG. 6a) which scrape undesired scale or deposits lining the conduit 20 as they vibrate back and forth. As previously indicated, the bundle of wires 14 and the reaming tool 2' can be made sufficiently small so that it can fit within a human artery or the like.

FIGS. 7 and 8 illustrate an application of the invention where the cylindrical utilization device 2 in FIG. 1 is replaced by spherical liquid agitating device 2'' comprising an inner core 2a'' of steel or similar metal surrounded by an outer layer 2b'' of material which has an acoustic impedance somewhere between the acoustic impedance of the bundle of wires 14 and a medium which is shown as a body of water or other liquid 24 within a vessel 26, into which liquid the device 2'' is immersed. The outer layer 2b'' may be, for example, Lucite or glass. The portion of the bundle of wires 14 extending into the vessel 26 is preferably surrounded by a casing 30 most advantageously of a sound reflecting material, such as neoprene or rubber to isolate the bundle of wires 14 from the water or other liquid 24, so that air surrounds most of the individually vibrating wires of the bundle to minimize loss of energy from the bundle before it reaches the agitating device 2''. The brazed end 16' of the bundle of wires 14 is securely anchored within an aperture 20' of a steel ball, as illustrated in FIG. 5.

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FIG. 9 shows an application of the invention wherein a number of bundle of wires 14 as described extending from individual sources of vibration 4 are connected at their farther ends to the same utilization device 31, so that multiple generators may be used to direct an extremely large amount of energy into a relatively small utilization device 31.

FIG. 10 illustrates an on-line emulsifier unit including a hollow conduit 32 forming a utilization device to be sonically vibrated. The ends of individual bundles of wires 14 are connected to longitudinally spaced points of the conduit to vibrate the walls of the conduit to aid in emulsifying a liquid 24' passing through the conduit.

Refer now to FIG. 11 which shows still another application of the invention. As there shown, the bundle of wires 14 couples the vibrations of the large sonic transformer 4 to an agitation device 35 having a bottom end portion extending into a body of molten metal or plastic 37 contained within a mold or vessel 38. (The sonic agitation of molten metal is a well proven desirable way for improving the quality and structure of certain metal alloys.) The agitating device 35 may comprise steel core 35a surrounded by a high temperature ceramic metal material 35b. It is important to isolate the sonic transformer driving transducer, which may include high temperature sensitive piezoelectric ceramic or magnetic stric-
 tive materials from the high temperatures in the vicinity of the body of molten metal 37, which could be as high as 4000° F. As illustrated, the bundle of wires 14 which may have any orientation remains completely outside of the body of molten metal 37 and is most advantageously cooled by means of a fan 40 or the like blowing cold air or water spray over and through the bundle of wires 14.

Refer now to FIG. 12 which shows a still further embodiment of the invention wherein a single sonic transformer 4 is coupled by the bundle of wires 14 to a number of different utilization devices 40a, 40b and 40c by splitting the bundle of wires 14 into a number of smaller bundles of wires 14a, 14b and 14c respectively extending to the utilization devices 40a, 40b and 40c.

Refer now to FIG. 13 which illustrates the use of the present invention where the power levels required to drive a portable hand held tool are so great that the source of vibrations comprising an electrical transducer 10 and the sonic transformer 4 must be supported on a cart frame 50. As there shown, a bundle of wires 4 enclosed by a protective casing 52 extends between the end of the sonic transformer 4 and a portable, light-in-weight tool unit 54 including a hand grip 56 and a trigger-like control 58' which controls the energizing and de-energizing of the electrical transducer 10. The assembly 54 further includes a vibrating tool bit 58 which is vibrated by the sonic waves propagated through the bundles of wires 14.

The present invention has still other applications. For example, the end of the bundle of wires 14 may be connected to the housings of very small orifice jets, to sonically clean the same, or to wire drawing tools to reduce friction between the wire and the tool through which it is drawn, or to machine cutting tools, or to surface abrading tools.

From the applications of the invention described above, it should be apparent that it is highly advantageous to use a bundle of a very large number of wires 14 to transmit sonic wave vibrations at high power levels to utilization devices most desirably having acoustic impedances at least roughly matching that of the wires. Such a vibration transmission means greatly increases the uses and applications of ultrasonic energy since bulky high power sonic generator equipment can be readily and permanently or temporarily mounted in any convenient location and then simply connected to remotely located utilization devices through flexible bundles of wires terminating in properly designed connectors which can be readily threaded onto or otherwise connected to the utilization device desired.

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Also, as above indicated, the use of fine flexible wires as described permits the application of high energy sonic vibrations to exceedingly small utilization devices located in small normally inaccessible spaces.

Numerous modifications may be made in the various forms of the invention described without deviating from the broader aspects of the invention.

It should be understood that the reference to a "bundle of wires" used in the claims to follow is to include a string of wire bundle section of any length secured together by connectors as shown in FIG. 5 or a single bundle of wires as shown in the other figures where each of the wires in the bundle is a continuous wire piece between the source of vibrations and the utilization device.

I claim:

1. In combination with a source of longitudinal vibrations having an intensity of at least about 1 watt/cm.², and a utilization device to be vibrated thereby, the improvement comprising a vibration transmission system which interconnects said source of vibrations and utilization device positioned remotely from one another, said vibration transmission system comprising: a flexible bundle of at least several dozens of wires fixedly connected at one end to said source of vibrations so said longitudinal vibrations thereof extend in the direction of the length of the wires and at least contacting said utilization device at the other end so longitudinal waves are propagated separately along each of the wires to the utilization device, each of said wires having a thickness which is much less than a quarter wavelength of said vibrations.

2. The combination of claim 1 where said other end of said bundle of wires are rigidly connected to said utilization device and the acoustic impedance of said utilization device at least roughly matches the acoustic impedance of said bundle of wires.

3. The combination of claim 1 wherein said source of vibrations is driven by an electrical transducer which converts electrical energy to vibration energy.

4. The combination of claim 1 wherein the medium between the wires in the bundle has an acoustic impedance many orders different from that of the wires.

5. The combination of claim 1 wherein at least part of said source of vibrations is much larger in cross section than the bundle of wires and said utilization device, so the end of the bundle of wires and the utilization device can fit within a space many times smaller than said source of vibrations.

6. The combination of claim 1 wherein said bundle of wires comprises at least one hundred wires.

7. The combination of claim 1 wherein said bundle of wires extends along a non-linear path.

8. The combination of claim 1 wherein the wires in the bundle are surrounded by a medium having an acoustic impedance many orders less than that of the bundle of wires.

9. The combination of claim 8 wherein the medium surrounding the wires is air or other gas.

10. The combination of claim 1 wherein the utilization device is immersed in a liquid medium and there is provided around the bundle of wires a sheath which keeps the liquid medium separated from the bundle of wires by a gas.

11. The combination of claim 1 wherein there are a number of sources of vibration each connected by a bundle of wires like said bundle of wires to said utilization device to be vibrated.

12. The combination of claim 1 wherein said bundle of wires and said utilization device are of a size to fit within a human blood vessel.

13. The combination of claim 1 wherein said utilization device is a single vibratable member for removing surface scales or coatings.

14. The combination of claim 1 wherein said utilization device is a reaming tool for cleaning conduits.

15. The combination of claim 1 wherein said utilization device is the wall of a container.

16. The combination of claim 1 wherein the opposite end portions of the wires are bonded together to form rigid integral connecting portions joined respectively to said source of vibrations and said utilization device.

17. The combination of claim 1 wherein there are a number of utilization devices respectively sonically coupled by individual bundles of wires like said bundle of wires to said source of vibrations.

18. The combination of claim 1 wherein each of said wires in said bundle of wires has a length to diameter ratio of at least about 100:1.

19. The combination of claim 6 wherein each of said wires in said bundle of wires has a length to diameter ratio of at least about 100:1.

20. In combination, a source of vibrations, a medium to be vibrated by said source of vibrations which medium has a temperature which would adversely affect said source of vibrations, means for transmitting said source of vibrations to said medium comprising a flexible bundle of at least several dozens of wires fixedly connected at one end to said source of vibrations where the individual wires of said bundle are separately vibrated longitudinally thereof, the other end of said bundle of wires extending to said medium and including an agitating body rigidly connected to the other end of said bundle of wires.

21. The combination of claim 20 wherein there are spaces between wires and there is provided means for circulating a cooling medium over said bundle of wires

to minimize the coupling of heat from said medium to said source of vibrations.

22. The combination of claim 1 wherein said longitudinal waves comprise essentially the only waves propagated along said bundle of wires.

23. In combination, a source of vibrations of such substantial weight that it cannot be readily manually lifted and manipulated, a hand-held, relatively light-in-weight, portable, tool assembly having a vibratable tool bit, and a vibration transmission system which interconnects said source of vibrations and tool bit, said vibration transmission system comprising a bundle of wires fixedly connected at one end to said source of vibrations so the longitudinal vibrations thereof extend in the direction of the length of the wires and at the other end to said tool bit so longitudinal waves are propagated separately along each of the wires to the tool bit.

References Cited

UNITED STATES PATENTS

3,245,892	4/1966	Jones	-----	259—Vib. Sonic
3,335,443	8/1967	Parisi et al.	-----	15—22
3,352,303	11/1967	Delaney	-----	128—303X

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15—22; 128—24, 303; 259—1