June 23, 1970 J. P. ARNDT 3,516,645

ULTRASONIC CLEANER

Filed Aug. 14, 1967 2 Sheets-Sheet 1

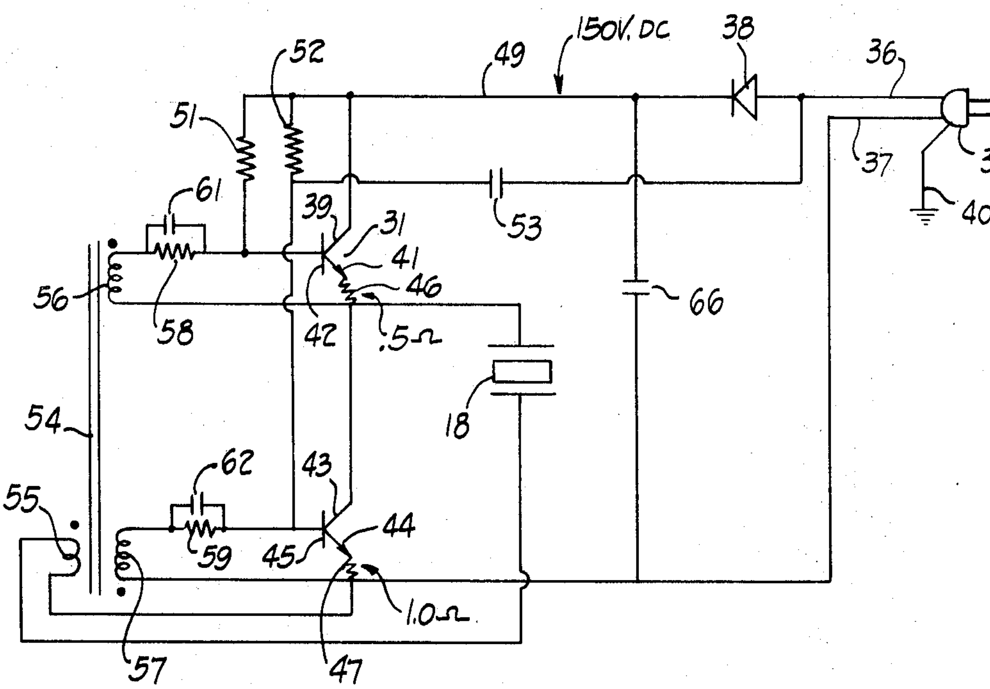

Fig. 1

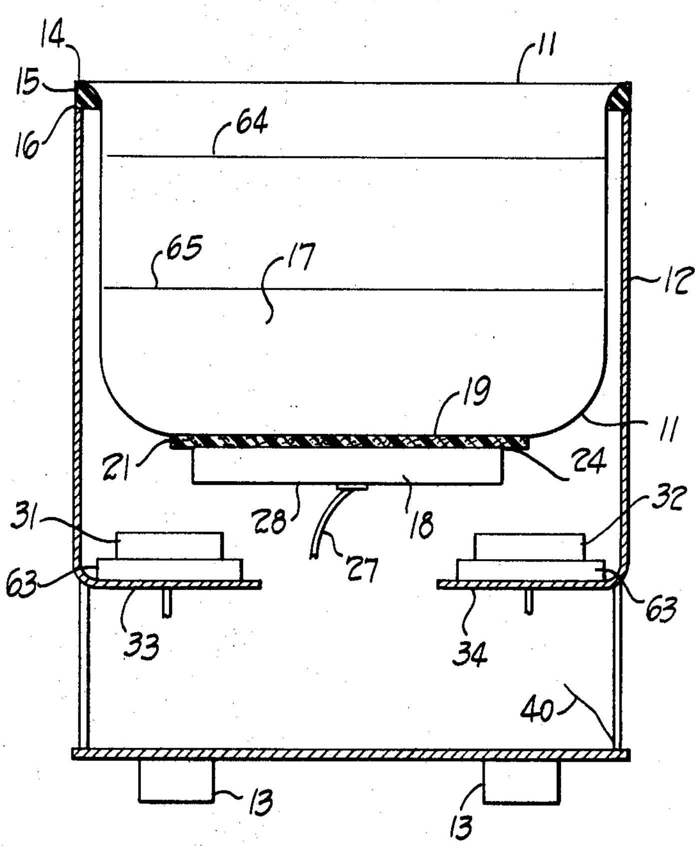

Fig. 2

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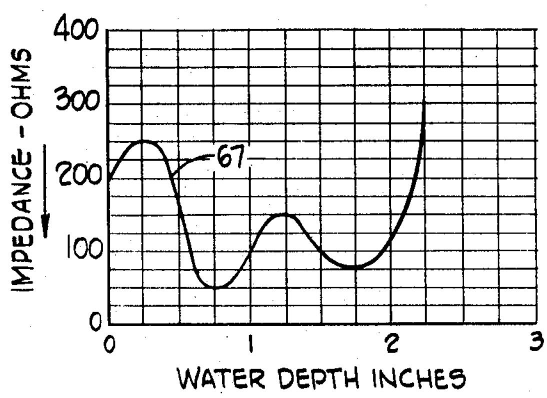

Fig. 3

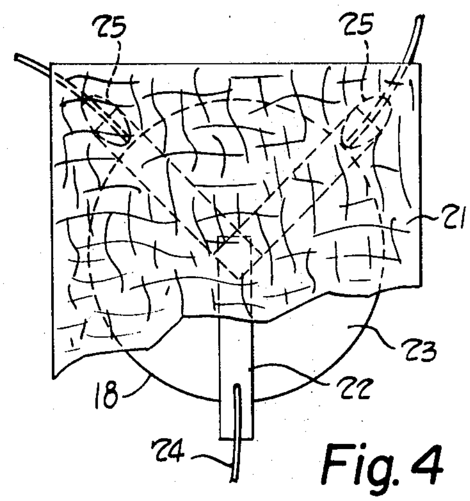

Fig. 4

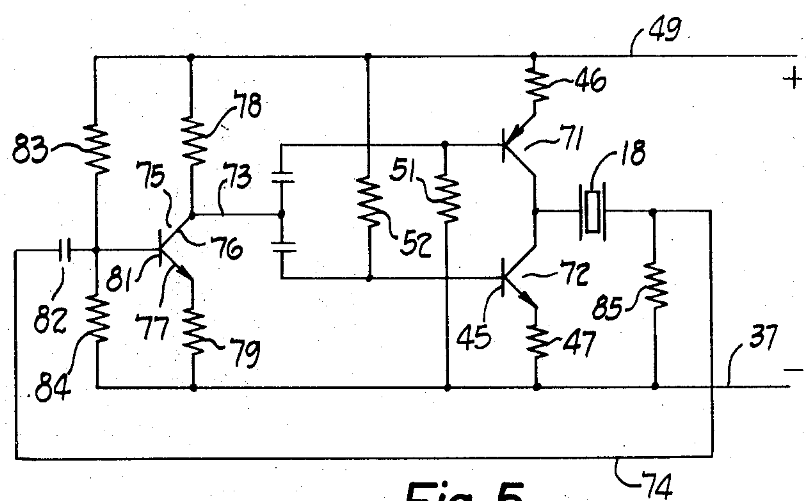

Fig. 5

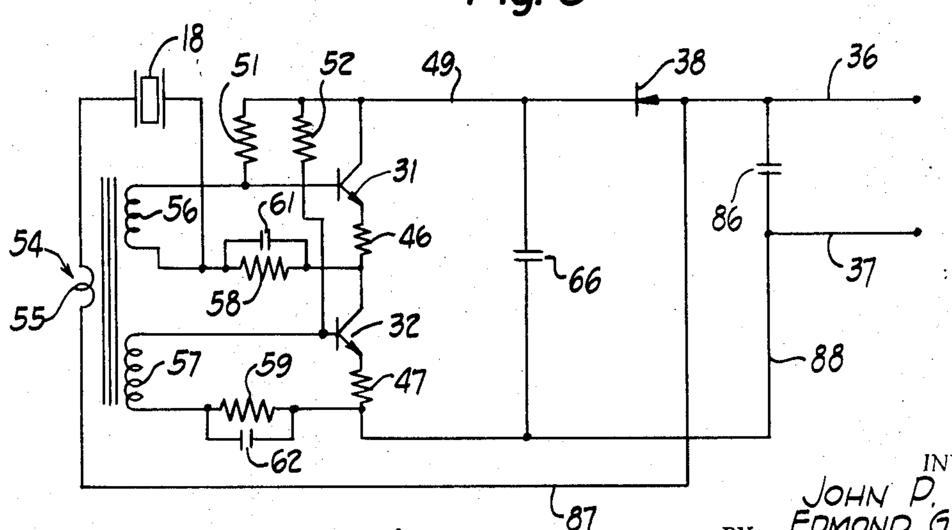

Fig. 6

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ULTRASONIC CLEANER

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Int. Cl. B01f *11/02*

U.S. Cl. 259—72 6 Claims

ABSTRACT OF THE DISCLOSURE

An ultrasonic cleaner is formed with a tank for containing liquid and articles to be cleaned with a ceramic piezoelectric transducer bonded to a surface of the tank for producing ultrasonic vibrations of the liquid therein. The piezoelectric transducer is driven by a switching circuit having transistors connected in series, and with the transducer connected in series with a feedback circuit to the bases of the transistors.

It is an object of the invention to provide efficient durable cleaning apparatus producing caviation by ultrasonic vibrations in the cleaning liquid, which apparatus may be manufactured easily and economically.

Other and further objects, features, and advantages of the invention will become apparent as the description proceeds.

In carrying out the invention in accordance with a preferred form thereof a substantially cylindrical sheet metal case is provided with an open top for receiving a cup shaped stainless steel tank having a lip gasketed to the upper edge of the case to provide both a resilient mounting and a water-tight, electrically insulated joint. A disc of low-loss piezoelectric ceramic material is bonded to the bottom surface of the cleaning tank with a layer of fiber glass interposed to insulate the transducer from the tank. This makes it possible to connect one side of an alternating current line directly to the transducer without producing a shock hazard for a person handling the apparatus. A low-loss epoxy resin is employed for bonding the fiber glass and the transducer to the tank.

For resilient support, rubber feet are provided for the sheet metal case. The case is preferably formed of a sheet material such as aluminum which has relatively high thermal conductivity, and portions of the outer walls of the case are bent inward to form horizontal brackets for supporting transistors utilized in a transducer-driving, switching circuit and acting as a heat sink for the transistors.

A better understanding of the invention will be afforded by following detailed description considered in conjunction with the accompanying drawings in which:

FIG. 1 is a circuit diagram of the driving circuit for the transducer employed in the cleaning apparatus.

FIG. 2 is a view of a section of the apparatus cut by a vertical plane.

FIG. 3 is a graph illustrating the relationship between transducer impedance and depth of liquid in the cleaning tank.

FIG. 4 is a plan view of the transducer and connections,

FIG. 5 is a circuit diagram of an electronic switching circuit for the transducer requiring no transformers and,

FIG. 6 is a circuit diagram of a modified arrangement producing frequency modulation of the transducer oscillation.

Like reference characters are utilized throughout the drawing to designate like parts.

In the embodiment of the invention illustrated in FIG. 2, there is a receptacle or tank **11** composed of a suitable

material such as stainless steel, e.g., for holding a liquid for subjecting material to be cleaned to the effect of ultrasonic vibration. Preferably the tank **11** is resiliently mounted. For example, a supporting case **12** may be provided having resilient feet **13** composed of a suitable material such as natural or synthetic rubber, for example. In order that the tank may be resiliently mounted in the case **12** with a liquid-tight seal thereto, the tank **11** is preferably formed with a lip **14** resting upon a gasket **15** at the upper edge **16** of the case **12**. For providing an effective resilient seal, a suitable material such as silicone rubber is employed for the gasket **15**. The case **12** in the embodiment illustrated is composed of sheet material, preferably a material having good thermal conductivity. For example, case **12** may be composed of spun or drawn aluminum sheet material.

For producing ultrasonic vibration of the tank **11** and the contained liquid **17** a suitable transducer **18** is provided. It is essential that the transducer **18** be composed of relatively low loss material in order that adequate driving power may be obtained without excessive heating of the transducer or material used for bonding it to the tank **11**. Although the invention is not limited to the use of a particular composition, it has been found that satisfactory results are accomplished by employing a polarized dielectric ceramic composed of lead titanate and lead zirconate with additives in proportions described in Pat. No. 2,906,710 issued to Kulcsar and Cmolik and manufactured in the manner described in said patent. For example, a disc may be employed comprising solid solution of lead zirconate, lead titanate, and additives. An alkaline earth element such as calcium and strontium is substituted for one to thirty atom percent of the lead. The mole ratio of lead and alkaline earth zirconate to lead and alkaline earth titanate in the solid solution is in the range from 65:35 to 45:55. A still lower loss material may be employed, if desired, such as lead titanate, zirconium titanate with additives and substituents as described in the copending application of Don Berlincourt and Laurence R. Sliker, Ser. No. 651,875 filed July 7, 1967 and Pat. No. 3,068,177 issued to Sugden.

Preferably the transducer **18** is in the form of a disc polarized transversely and driven at a frequency such that the drive frequency corresponds to the resonant vibration frequency of the disc in its radial mode. Accordingly, the tank **11** is formed with a suitable flat or plane surface to which the disc shaped transducer **18** may be bonded. As shown, the tank **11** is in the form of a cup having a flat bottom **19** and the disc **18** is chosen with a diameter of the same order as the diameter of the planar surface of the botom **19**. It is essential that a low-loss bonding material be employed for securing the transducer **18** to the bottom surface **19** of the tank **11** to prevent the generation of such losses in the bonding material as to heat it to the softening point. Preferably a low-loss type of epoxy resin is employed such as that for example sold under the trade name Ecco Bond #45 (rigid formulation: one part catalyst #15, 2 parts Ecco Bond #45), or Shell Epon 6.

In order to avoid the possibility of a shock being received by a person touching the tank when one side of the alternating current line is connected to the transducer, the transducer **18** is insulated from the bottom **19** of the tank **11** by interposing a sheet of fiber glass cloth **21** which is in turn bonded both to the tank bottom **19** and the upper surface **23** of the transducer **18** by the low-loss epoxy resin or cement material. Open mesh fiber glass cloth such as is used in auto body repairing is employed with a thickness, for example, of .012 inch.

Preferably in order to insure a good bond, the tank **11** is first cleaned with solvent and roughened with emery cloth before bonding. To assure a good joint, preferably pressure is maintained on the joint for a period of about 12 hours while the epoxy resin is curing. This may be accomplished by placing a weight on the disc.

It will be understood that piezoelectric transducers such as the disc **18** are customarily fabricated with silvered surfaces as shown in FIG. 4.

For making electrical connections to the surfaces of the piezoelectric transducer **18** conducting strips **22** are applied to the upper silvered surface **23**, the cemented surface. For example, in the case of a stainless steel cleaning tank having internal dimensions of 3½ by 3½ inches, 2½ inches deep, a disc of piezoelectric material 2⅛ inches in diameter and ¼ inch thick is cemented to the bottom of the tank and in this case the electrical connections at the cemented surface may be made by .002 inch silver foil strips placed at 120 degrees spacing. Although soldering to the silvered surface **23** on the disc is not necessary, this is considered advantageous in production work.

Superior results are obtained when the tank has rounded corners, particularly around the bottom edge of the tank and the junction between the side walls and the bottom which carries the transducer disc. Although the invention is not limited to a particular radius, satisfactory results have been obtained with a radius of about ¼ inch to ½ inch. Operation has been found to be inferior when the radius is as small as 1/32 inch. In the case of a 2½ inch tank the radius is of the order of ten percent of the depth of the tank.

Although we are not able to explain the exact theory involving this feature, we believe that when the corners are rounded, more ultrasonic energy is transmitted up the sides of the tank into the liquid, thereby improving the distribution of energy throughout the tank.

Better cleaning is ordinarily obtained with relatively low vibration frequencies, preferably relatively close to the audible limit of frequency. Such low frequency has heretofore been difficult to obtain by the operation of the transducer disc in the thickness mode. Such low frequencies would ordinarily require a very thick resonant oscillator disc or the attachment of a mass to lower the frequency. A thin disc with a large diameter makes it possible to get along with very little piezoelectric material because the diameter of the disc controls the frequency.

Increasing the diameter of the piezoelectric disc makes it possible also to transfer a greater amount of power to the oscillator disc.

In order to enable the utilization of a larger diameter disc, the disc may, if desired, be made of a greater diameter than the bottom plane surface of the tank.

For reliability, lead wires **24** are connected to all three strips **22** and the foil wire connections are buried in epoxy resin **25** to prevent the foil from fraying by ultrasonic vibration. For the second electrode a flexible wire **27** is soldered to the lower or outer silvered surface **28** of the disc **18**.

A suitable electrical circuit is utilized for applying voltage to the conductors **24** and **27** of the requisite frequency for maintaining ultrasonic vibration. Preferably a switching circuit is utilized employing a pair of series connected transistors **31** and **32**. For mounting the transistors **31** and **32**, shelves or brackets are formed in the case **12** by cutting, and bending in portions **33** and **34** of the sheet material. Since the case **12** is composed of a good thermal conductor such as aluminum sheet material, the transistor supporting shelves **33** and **34** serve as heat sinks for the transistors.

A switching circuit for driving the piezoelectric transducer **18** is illustrated in FIG. 1. Utilizing a standard 115 volt alternating current as source, 100 to 150 volts of direct current is available in the circuit. The alternating-current supply is represented by a cap **35** which is preferably of a 3-wire type in order that a mechanical ground wire **40** can be brought out in addition to live conductors

36 and **37**. The transistors **31** and **32** are connected to the conductors **36** and **37** in series with a rectifier **38**. Although the invention is not limited to the use of NPN transistors, in the circuits shown by the way of illustration the transistors **31** and **32** are of the NPN type. The transistor **31** has a collector **39**, an emitter **41** and a base **42**. Similarly, the transistor **32** has a collector **43**, an emitter **44** and a base **45**.

For starting the switching circuit positive current bias is provided for the bases. This is accomplished in the circuit illustrated by providing resistors **51** and **52** each connected by a conductor **49** to the rectifier **38** and connected to the bases **42** and **45** respectively. For supplying an alternating-current starting signal, a condenser **53** may be connected between the alternating current supply line **36** and the base **45** of the transistor **32** across which the piezoelectric transducer **18** is connected.

For driving the bases **42** and **45** a transformer **54** is provided, having a primary winding **55** in series with the piezoelectric transducer **18** and a pair of secondary windings **56** and **57**. As indicated in the drawing, the transformer is a current step-down transformer. The secondary winding **56** is connected between the base **42** and the emitter circuit of the transistor **31** and the secondary winding **57** is connected between the base **45** and the emitter circuit of the transistor **32**. As indicated by the conventional dot representation in the drawing, the polarities of the windings are such that the windings **56** and **57** are oppositely connected to the transistor bases and the upper ends of the windings **55** and **56** are of the same polarity.

Emitter resistors **46** and **47** are provided in series with the emitters **41** and **44** respectively. The circuits of the secondary windings **56** and **57** include base resistors **58** and **59** respectively. For improving the wave form of the switching circuit speed-up capacitors **61** and **62** are connected across the base resistors **58** and **59** respectively. The polarities of the secondary windings **56** and **57** are reversed on the two transistors **31** and **32**; so that one is driven on while the other is driven off.

For safety purposes and reducing the shock hazard, the mechanical ground wire **40** from cap is run to the aluminum base.

The apparatus is designed for operation at approximately 43 kilocycles. At this frequency the transformer **54** may be of somewhat lighter and less expensive construction than transformers at central-station, power frequencies and relatively few turns of winding are required. In the particular embodiment illustrated for a ratio of 1 to 10 current step-down, the primary winding **55** may have a single turn and each of the two secondary windings, **56** and **57** may have 10 turns.

The transistors **31** and **32** are electrically insulated from the shelves or brackets **33** and **34** upon which they are mounted although arranged for good thermal conductivity to the heat sink material of the case **12**. This may be accomplished by employing mica washers **63** coated with silicone grease as insulators.

Preferably, the preferred depths of liquid in tank **11** are indicated by scribed lines **64** and **65**.

Although the apparatus is not limited to the use of water as a liquid in the cleaning tank **11**, ordinarily water will be employed as the most economical liquid.

Since the energy required to cavitate water decreases as the water temperature increases, it is desirable to use lukewarm water in the cleaning tank **11**. A suitable wetting agent should be added to the water. For example, a readily available household detergent such as a dishwashing detergent sold under such trade names as Joy, Liquid Lux, or the like may be employed. A few drops, which should be stirred in before operating the unit, are all that is needed. The water cavitates more readily after it is de-gassed. A few minutes operation will accomplish this.

Since the piezoelectric disc **18** is closely coupled to the tank and the water load, the water depth in the tank affects the power transferred to the water and the frequency of the transducer **18**. The variation of the transducer impedance with water depth is shown by the sinuous curve **67** in the graph of FIG. 3. In the case of the embodiment with the dimensions given by way of illustration, the low impedance points are water depths of approximately ¾ inch and 1¾ inches. In FIG. 3 the impedance in ohms is plotted vertically against water depth in inches plotted in a horizontal direction.

The cleaner should be operated at one or the other of these low impedance points. For example, the ¾ inch depth (which gives maximum cavitation) is suitable for cleaning dentures, shaver heads, jewelry, fountain pen points, spark plugs, small tools, etc. The 1¾ inch depth (or higher) is useable for eye glasses, silverwear (which is cleaned first at one end and then at the other), kitchen tools, etc.

For most cleaning a simple detergent solution such as Joy is sufficient. However, since it must be realized that ultrasonic cleaning is a scrubbing process, the proper solvent which can attack or dissolve the particular soil is desirable.

Although the invention has been described as carried out by employing a single cleaning tank with the ultrasonic transducer secured to the lower surface of the tank, it will be understood that the invention is not limited thereto and does not exclude the use of a tank with the transducer mounted on the side nor does the invention exclude the use of a pair of tanks mounted side by side with a transducer between them. If two tanks were used in this manner, each tank would tune the transducer and one tank would be used for cleaning and the other for rinsing.

The invention is not limited to the use of apparatus with particular electrical or mechanical dimensions. However, satisfactory results have been obtained when the parts were of the type or dimensions listed as follows:

Transistors **31** and **32**—Delco DTS-410
Rectifier **38**—RCA silicon rectifier IN-3194
Filter capacitor **66**—Sprague TVA-1414, 50 mf., 150 v.
Starting capacitor **53**—1000 micromicrofarads
Speed-up capacitors **61** and **62**—Sprague 2249-R-75 0.25 microfarad
Transformer **54**—Toroid, Indiana General CF 108, Composition H
Base resistors **58** and **59**—30 ohm, ¼ watt
Emitter resistor **47**—1 ohm, ¼ watt
Emitter resistor **46**—.5 ohm, ¼ watt
Biasing resistor **51**—4700 ohms, 1 watt
Biasing resistor **52**—5000 ohms, 4 watts
Piezoelectric transducer **18**—2⅛ inch diameter by ¼ inch thick

It will be observed that preferably biasing resistors **51** and **52** differ slightly in resistance and likewise the emitter resistors **46** and **47** differ in resistance. The biasing resistor **52** for the transistor **32** which has the piezoelectric transducer **18** connected across it is made slightly greater in resistance than the other biasing resistor **51**. Correspondingly, the emitter resistor **47** for the transistor **32** is made greater in resistance than the emitter resistor **46** for the transistor **31**.

The expense and weight of transformers may be avoided by utilizing other means for producing alternate switching of the series transistors and providing the requisite phase inversion for positive feed-back to maintain oscillation. For example, as illustrated in FIG. 5, complementary transistors **71** and **72** may be employed, that is transistors of opposite types, one being a PNP and the other an NPN type transistor. As shown the transistor **71** is a PNP transistor and the transistor **72** is an NPN transistor. In this manner a single coupling connection **73** may be employed for producing opposite effects at bases **42** and **45** of the transistors **71** and **72**, respectively, so that a base signal of a given polarity will turn one transistor on and the other off.

Phase inversion in the feed-back line **74** to produce a positive feed-back for maintaining oscillation may also be accomplished without a transformer by utilizing a suitable phase inverter such as a phase inversion stage comprising a transistor **75** also connected between the direct-current input lines **49** and **37**. The transistor **75** is shown as an NPN type with a collector **76** connected to the positive direct-current line **49** and an emitter **77** connected to the negative line **37** in series with resistors **78** and **79** respectively. The transistor **75** has a base **81** coupled through a condenser **82** to the feed-back line **74**.

The use of a tank with rounded corners in providing a distribution of energy accomplishes some of the effects of using a frequency modulation system for breaking up energy concentrations. However, actual frequency modulation may be accomplished in a relatively simple manner by taking advantage of the fact that the resonant transducers have a different natural frequency of oscillation for different electrical connections. Thus with the transducer alternately short circuited and shunted by an impedance, it will control circuit oscillation alternately at or near its resonance frequency and at a somewhat different frequency. In the arrangement illustrated in FIG. 6, the impedance shunting the transducer is different when the rectifier **38** is conducting than when the rectifier is not conducting.

Consider first a small increment of time during which the rectifier is conducting 60 Hz. current to charge filter capacitor **66**. During this time, conductor **87** is effectively connected to the positive side of filter capacitor **66** and the transducer is terminated by a low impedance circuit which may be traced from the transducer through transformer primary **55**, conductor **87**, conducting rectifier **38**, and then alternately through filter capacitor **66** and transistor **32**, and through transistor **31** (alternating at the oscillation frequency) and back to the transducer through capacitor **61** shunted by base resistor **58**. Filter capacitor **66** has low impedance at the oscillation frequency and accordingly it makes little difference insofar as terminating impedance is concerned whether transistor **32** is turned on forcing transducer current through capacitor **66**, or whether transistor **31** is turned on bypassing capacitor **66**.

Now consider the time interval during which rectifier **38** is not conducting due to polarity reversal of the 60 Hz. supply. During this time the circuit across the transducer may be traced from the transducer through transformer primary **55**, conductor **87**, through bypass capacitor **86** in parallel with the 60 Hz. line, through conductor **88**, and then alternately through transistor **32**, and through filter capacitor **66** and transistor **31** (alternating at the oscillation frequency) and back to the transducer through capacitor **61** shunted by base resistor **58**.

Capacitor **86** may have capacitance about equal to the static capacitance of the transducer or less. In fact, we have successfully operated with capacitor **86** omitted. It can be seen that during the time interval when the rectifier is not conducting, the circuit shunting the transducer includes the high frequency impedance of the 60 Hz. line shunted by capacitor **86**, and during the time that the rectifier is conducting, the impedance of the line shunted by capacitor **86** is effectively out of circuit. This alternate exclusion and inclusion of the impedance of the 60 Hz. line shunted by capacitor **86** depending on whether the rectifier is conducting or not, causes frequency modulation of the oscillator at a 60 Hz. rate.

The connection of the transducer to the 60 Hz. line through conductor **87** serves to apply 60 Hz. current to the base of transistor **31** to assist in starting oscillation, replacing capacitor **53** of FIG. 1.

In accordance with the provisions of the patent statutes the principle of operation of the invention has been described together with the apparatus now believed to represent the best embodiment thereof, but it is to be understood that the apparatus shown and described is only illustrative and that the invention may be carried out by other arrangements.

What is claimed is:

1. Cleaning apparatus comprising in combination a sheet metal case, a cleaning tank mounted resiliently therein with a gasket to seal confronting walls of the cleaning tank and the case, and an oscillator comprising in combination a resonant transducer, electric power supply terminals and an electronic switch in circuit with said supply terminals and said transducer, said switch being actuated by current drawn by said transducer, the switch comprising a pair of transistors in series with the power supply terminals, the tank having a surface to which the transducer is attached, the case being composed of sheet metal with portions bent in to form supporting brackets,
each of said transistors being mounted on one of said brackets, whereby the metallic case serves as a heat sink.

2. Cleaning apparatus comprising a cleaning tank adapted to receive liquid and articles to be cleaned, the tank having a plane surface, a disc of low-loss piezoelectric transducer material bonded to said surface with means for oscillating the transducer material, a case composed of sheet material of good thermal conductivity having portions bent to form brackets and having a shape conforming to that of the cleaning tank, the cleaning tank being provided with a lip fitting the upper edge of the case and an insulating resilient gasket between said lip and the upper edge of the case, the tank being in the form of a cup having a lower plane surface to which the piezoelectric disc is bonded, the piezoelectric disc being provided with an electric driving circuit including transistor means mounted on said brackets.

3. Cleaning apparatus as described in claim 2, wherein the disc is bonded to the tank surface with an open mesh layer of glass fabric interposed.

4. Cleaning apparatus as described in claim 3 wherein a low-loss epoxy resin is employed for bonding the piezoelectric disc and interposed glass fabric to the cleaning tank.

5. Cleaning apparatus as described in claim 4 wherein the tank is scribed at levels corresponding to minimum impedance when liquid is placed in the tank.

6. Cleaning system as described in claim 5 wherein the piezoelectric transducer comprises a dielectric ceramic body formed of a solid solution consisting essentially of lead zirconate, lead titanate and at least one alkaline earth element selected from the group consisting of calcium and strontium substituted for one to thirty atom percent of the lead in said zirconate and titanate, the mole ratio of lead and alkaline earth zirconate to lead and alkaline earth titanate in said solid solution being in the range from 65:35 to 45:55.

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259—1; 310—8.1