March 10, 1970 K. H. BRECH ET AL **3,500,089**

ULTRASONIC CLEANING APPARATUS

Filed May 9, 1967 3 Sheets-Sheet 1

FIG. 1

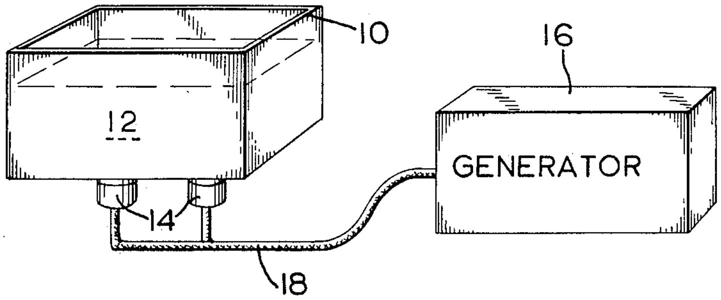

FIG. 2

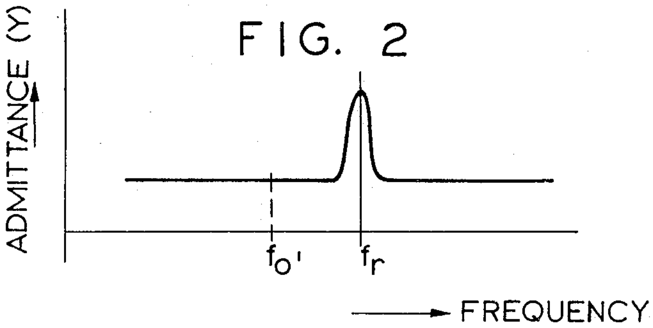

FIG. 3

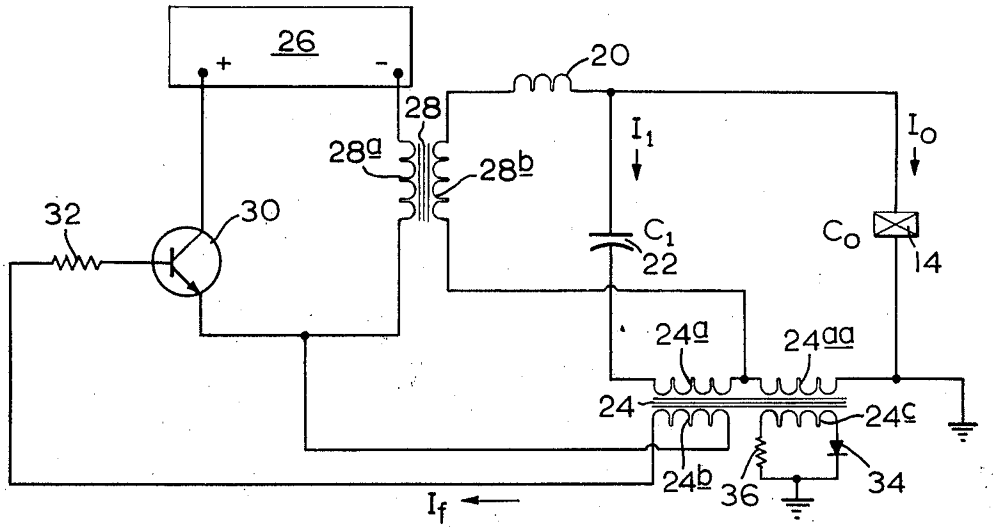

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FIG. 6

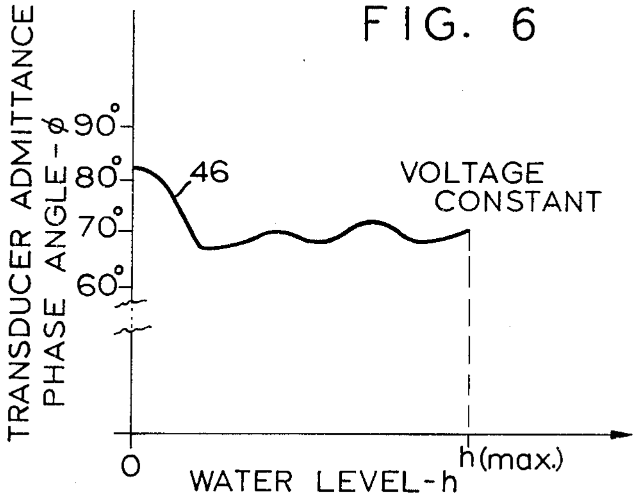


FIG. 4

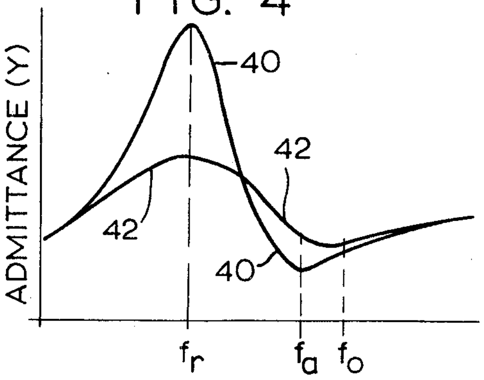


FIG. 7

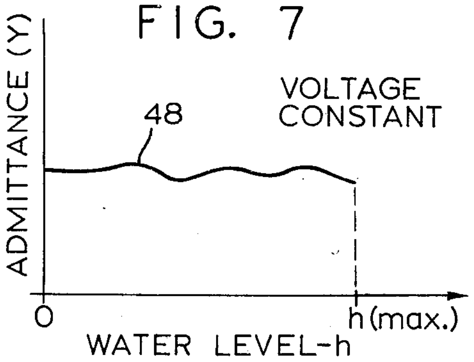
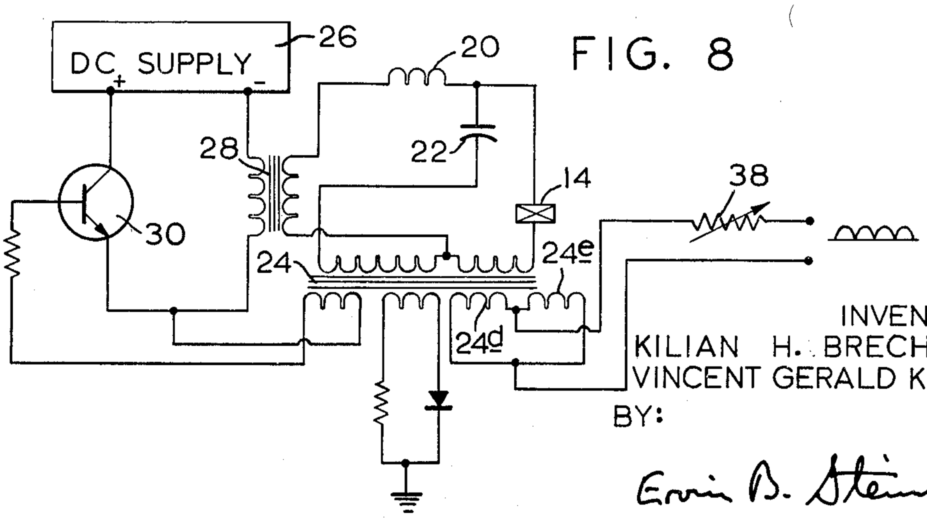


FIG. 8



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ULTRASONIC CLEANING APPARATUS

Filed May 9, 1967 3 Sheets-Sheet 3

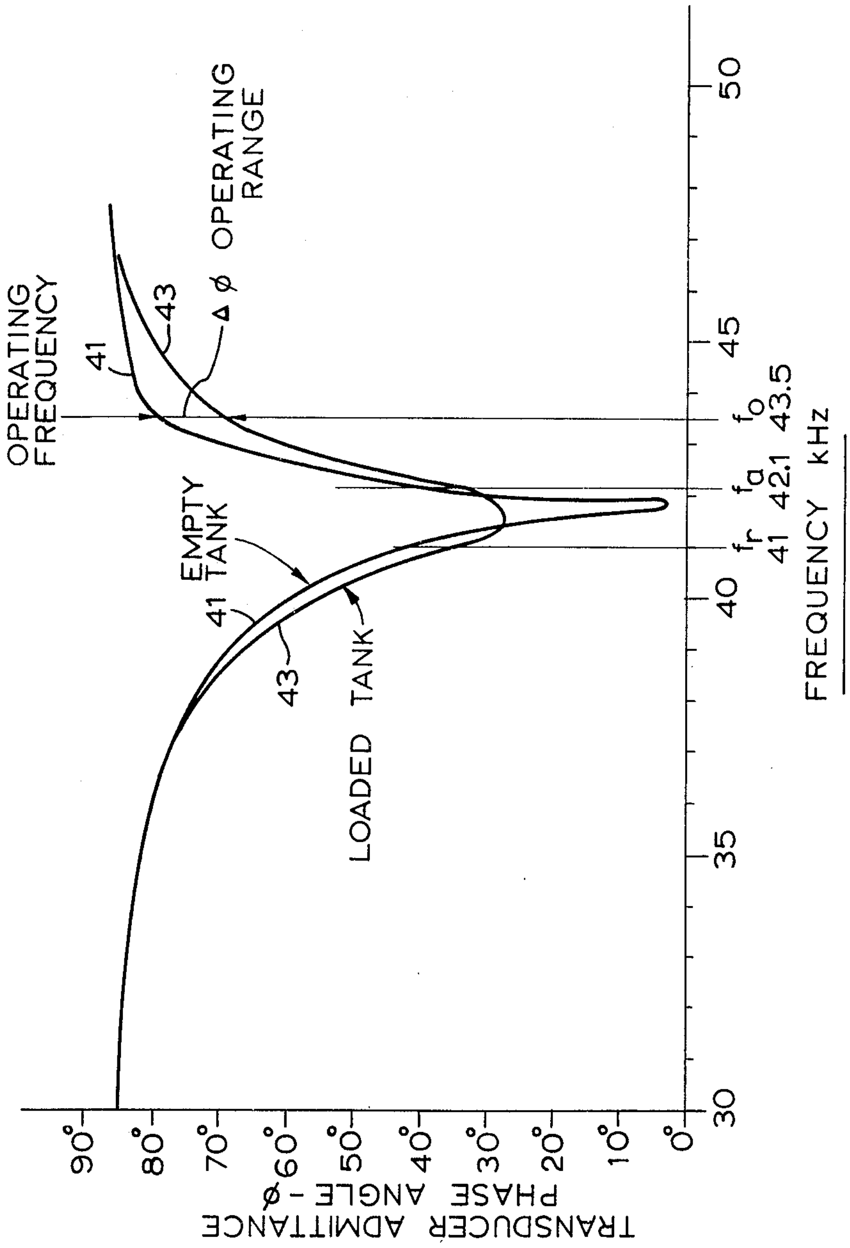

FIG. 5

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ULTRASONIC CLEANING APPARATUS

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Int. Cl. H01v 7/02
U.S. Cl. 310—8.1 18 Claims

ABSTRACT OF THE DISCLOSURE

An oscillatory circuit for an ultrasonic cleaning system which avoids the condition of current peaks in the transducer branch normally caused by resonance load conditions. The circuit, because of a feedback signal which decreases in amplitude as the current through the transducer branch increases, shifts the oscillator frequency in a manner to reject sharp resonance conditions. Additionally, the circuit is operated at a frequency above that of transducer antiresonance, minimizing the change of impedance versus frequency, thus enabling the parallel connection of transducers and cleaning tanks under different load conditions.

This invention refers to an ultrasonic cleaning apparatus as used in the industry and the medical field for cleaning various devices and instruments. Generally, an ultrasonic cleaning apparatus comprises a liquid-filled tank which is fitted with one or more ultrasonic transducers adapted to be energized by electrical high frequency energy, usually 20 kc./second or higher. Upon energization of the transducers, the electrical energy applied is converted to acoustic energy which produces cavitation in the liquid.

Transducers for the purpose described hereinabove are either of the magnetostrictive or of the electrostrictive (piezoelectric) type and are secured either directly to the tank enclosure, or are contained in a separate liquid-proof enclosure which is immersed in the liquid.

In the prior art various circuits are described for operating the transducers and the oscillatory circuit connected thereto at resonance. It is well known that the resonant frequency condition of the circuit is affected by the load impedance of the tank, such load impedance being a function of the liquid level of the tank as well as of the charge immersed in the liquid. While in the older systems manual tuning controls are provided in order to enable re-tuning of the oscillatory circuit as necessary, more recent cleaning systems employ automatic feedback control systems for maintaining the oscillatory circuit at or near true resonance despite varying impedance conditions.

Operating a cleaning tank at resonance, while considered to be efficient, is afflicted with several shortcomings. As the liquid level in the tank changes and goes through multiples of the resonant wavelength, the sonic power provided to the tank goes through extreme fluctuations. Automatic feedback systems attempt to minimize this effect. However, as the liquid level is reduced and the empty tank condition is approached, the power applied to the tank remains constant or increases, thereby damaging the tank by excessive mechanical vibration and by a lack of cooling liquid. Still further, because of the criticalness of tuning caused by the very steep change of the electrical admittance of the oscillatory system versus frequency at the region of resonance, it has been impossible to connect several cleaning tanks in parallel to a single high frequency generator, since substantially all power would flow to the tank having the lowest impedance. Even if automatic tuning control is used, it is impossible

to operate tanks in parallel unless such tanks are at the same water level and present the same load condition. Automatic control attempts lock on to the tank exhibiting the lowest impedance and at this locked-on frequency a particular tank coupled in parallel may exhibit a very high impedance. Therefore, automatic tuning does not overcome the stated problem.

The above stated shortcomings have substantially been eliminated by means of a novel oscillator arrangement wherein the ultrasonic cleaning system is operated under conditions in which the electrical circuit rejects the existence of high current peaks in the transducer, i.e. the circuit avoids the condition of load responsive resonant peaks (maximum electrical admittance of the transducer). This desirable circuit condition is accomplished by providing an electrical circuit which produces a decreased feedback signal to the driving portion of the oscillator when the current through the ultrasonic transducer branch tends to increase and, responsive to the existence of such condition, causes a small frequency shift away from the condition of the resonant peak. Additionally, in the preferred arrangement the oscillator circuit is set to operate at a frequency which is at least as high as the antiresonance frequency of the transducer and preferably is above the antiresonance frequency of the transducer. In this region, the circuit admittance is relatively constant, thereby permitting the parallel connection of a plurality of tanks to a single ultrasonic energy generator and providing satisfactory operation irrespective of the liquid level, load condition, or electrical impedance differences exhibited by paralleled tanks. If any particular tank connected in parallel should exhibit a low impedance at a given frequency, because of standing waves in the liquid or load, the generator, as stated above, changes the frequency of the oscillatory circuit slightly so as to eliminate this condition. Hence, tanks coupled in parallel virtually operate under the same power conditions.

One of the principal objects of this invention is, therefore, the provision of a new and improved circuit for ultrasonic cleaning systems, the circuit being characterized by avoiding transducer operation at undesirable electrical resonance conditions.

Another object of this invention is the provision of an ultrasonic cleaning system wherein the circuit operates at a frequency which is above that of resonance and, most suitably, above that of antiresonance of the transducer.

Another object of this invention is the provision of an ultrasonic cleaning circuit which provides for the parallel connection between a plurality of tanks and a high frequency generator.

A further object of this invention is the provision of an ultrasonic cleaning unit wherein the power supplied to a cleaning tank decreases with decreasing liquid level or decreasing load.

A still further object of this invention is the provision of an ultransonic cleaning unit operating at a frequency at which the criticalness of tuning is eliminated.

Further and still other objects of this invention will be more clearly apparent by reference to the following description when taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a schematic view of an ultrasonic cleaning arrangement;

FIGURE 2 is a schematic illustration for explaining the operation of the prior art arrangement;

FIGURE 3 is a schematic electrical circuit diagram of the present invention;

FIGURE 4 is a graph of electrical admittance versus frequency for a cleaning system;

FIGURE 5 is a typical graph of electrical phase angle versus frequency for a loaded and unloaded cleaning tank;

FIGURE 6 is a graph of electrical phase angle versus water level under typical operating conditions;

FIGURE 7 is a graph of electrical admittance versus water level for the conditions shown in FIGURES 5 and 6, and

FIGURE 8 is a schematic electrical circuit diagram depicting an improvement.

Referring now to the figures and FIGURE 1 in particular, there is shown a tank **10** which is filled with a suitable liquid, such as a cleaning solvent **12**. One or more ultrasonic transducers **14** are mounted to the bottom of the tank in order to provide sonic energy to the liquid **12** and cause cavitation therein. Each transducer, in the preferred embodiment, includes a piezoelectric element for converting electrical energy to mechanical energy and is of the clamped sandwich construction as shown for instance in U.S. Patent No. 3,066,232 issued to N. G. Branson, entitled "Ultrasonic Transducer," dated Nov. 27, 1962. The transducers, connected in parallel, exhibit a natural frequency of vibration, typically 25 or 40 kHz., and are energized from an electrical generator **16** via a conductor **18**. Also, as is well understood, the transducers, when energized, exhibit a predominantly capacitive current component responsive to the motional and clamped capacitance.

FIGURE 2 shows a graph of electrical admittance versus a very limited frequency range for a typical prior art ultrasonic cleaning unit. At the resonant frequency f_r there exists the condition of maximum electrical admittance (minimum impedance) caused by water level and load conditions. These peaks are repeated at one-half wavelength intervals of the resonant frequency. In the prior systems, which attempt to operate under the condition of lowest impedance, the frequency of the oscillatory system, if operating at the frequency f_o, shifts to the frequency f_r and locks on. In the system which will be described hereafter, if the quiescent value of the frequency is f_r, the frequency will change to a value of $f_r+\Delta f$, thereby rejecting the condition of maximum admittance and, hence, avoiding the existence of current peaks in the transducer branch resulting from resonance load conditions.

The electrical circuit contained in the generator **16** is shown in FIGURE 3. The basic circuit is a regenerative oscillator whose frequency is determined by the inductances which include the series inductance **20** and the transformer **24**, and the capacitances which include the transducer or transducers **14** and that of the capacitor **22** connected in parallel with the transducer. In the preferred embodiment, the values of the inductance **20** and of the capacitor **22** in combination with the transducer **14** are chosen to provide for the operation of the oscillatory circuit at a frequency which is not below that of antiresonance and preferably above that of antiresonance of the transducer. The capacitor **22** and the transducer **14** are coupled to each other through a summing means comprising the primary winding **24***a* and the opposing winding **24***aa* of the transformer **24**. The value of the capacitor **22** and the turns ratio of the windings are selected in such a manner that the current responsive signal from the capacitor **22** (I_1) exceeds the current (I_o) through the transducer **14**, thereby providing in the secondary winding **24***b* a signal I_f which is the difference of the subtraction I_1 minus I_o and whose value remains positive.

The load circuit, comprising the transducers and the other components of the oscillatory circuit, is driven by a direct current supply **26** which is connected to the primary winding **28***a* of a power transformer **28** and a controlled switching means **30**, such as a transistor. The secondary winding **28***b* of the transformer **28** is connected to the inductance **20** of the oscillatory circuit and to the center tap of the primary winding of the transformer **24**. The first secondary winding **24***b* of the transformer **24** provides the feedback signal and is connected in series with a resistor **32** to the switching means **30**. This connection produces an alternating current signal which must be in phase with the current in the oscillatory circuit in order to sustain the oscillations of the oscillatory circuit. The transformer **24** is provided with a second secondary winding **24***c* which is connected to the series connection of a rectifier **34** and a resistor **36**. During the half cycle when the switching means **30** is rendered conductive, a pulse of current is provided via the transformer **28** to the oscillatory circuit. During the following half cycle, when the switching means **30** is non-conductive, the diode **34** and the resistor **36** present a load circuit which is reflected by the transformer **24** in the oscillatory circuit, thus, obtaining a relatively symmetrical output wave across the transducers **14**.

In the preferred embodiment, assuming an equal quantity of turns for the windings **24***a* and **24***aa*, the capacitor **22** is selected to have a capacitance which is larger than the capacitance presented by the piezoelectric transducer or transducers in order that the current I_1 predominates. If the current I_o through the transducer increases because of a resonance condition which causes a lowering of the impedance presented in the transducer branch of the circuit, the magnitude of the feedback current I_f, which is the difference of I_1-I_o, is reduced, causing a slight shift in frequency and thereby discouraging the circuit from locking on to a peak current condition in the transducer branch, i.e. the condition sensitive to the existence of half wavelength resonance produced by the load.

The behavior of this circuit appears to be governed by the ratio:

$$\frac{\Delta\omega}{\Delta(R_L{}^n)}=\text{negative number}$$

wherein

$\Delta\omega$=change in frequency
ΔR_L=change in load resistance
$n=>0$

As is apparent, an increase in the load resistance causes a decrease of the frequency of the oscillatory circuit and vice versa.

Referring now to FIGURE 4, the curve **40** represents the familiar electrical admittance versus frequency curve of the oscillatory circuit for an unloaded cleaning tank. Curve **42** represents the same tank when loaded. It will be noted that the admittance is a maximum at the resonant frequency f_r of the transducer and is near its minimum in the region of transducer antiresonance f_a. In the past great effort has been made to maintain cleaning systems of this type at the point of resonant frequency f_r. As will be noted, tuning of the system for resonance is very critical for an empty or unloaded tank and somewhat less critical for a loaded tank. The present invention, as indicated above, prefers operation of the system at a frequency which is above that of the antiresonance frequency of the transducer, that is, at the frequency f_o. In this region the electrical admittance does not change sharply with a change of frequency, as is the case at the point f_r or f_a and the frequency, therefore, can be varied from a center frequency without a large change in the circuit impedance. Therefore, several cleaning tanks with moderately varying impedances can be connected in parallel to a single generator.

The circuit as disclosed hereinabove has other desirable characteristics, notably the change in transducer admittance phase angle at the no load condition, that is, the empty tank condition at which the value for R_L becomes large, no power being transferred to an external load. In FIGURE 5 the curve **41** represents the empty tank and the curve **43** represents the loaded tank, in this case plotting phase angle of the electrical power of the oscillatory circuit versus frequency. The operating point f_0 is selected to be at a frequency which is above that of antiresonance and to be one at which there is a relatively large change in the value of the cosine of the phase angle for the condition from an unloaded tank to a loaded tank. Since the average power dissipated is the product of peak voltage and peak current divided by two, multiplied by the cosine of the phase angle, it is apparent that the change of value of the cosine is of great importance. It has been noted that at the operating point f_0 in the particular system tested, the unloaded tank causes a leading phase angle of approximately 80°, while the loaded tank shows a leading phase angle of approximately 70°. The cosine of 80° is 0.17 and the cosine of 70° is 0.34. Hence, there is typically a change of power over a range of 1:2. The effective power diminishes as the empty tank condition is reached. This latter characteristic is most desirable and is just the opposite of that which is experienced with circuits operating at the resonant frequency where the power is constant, or even increases, as the tank is unloaded. It will be apparent that the reduction of the power as unloading occurs is a most desirable feature and protects the tank and the transducers.

The advantageous operating characteristic described above is depicted also in FIGURE 6 wherein the curve **46** shows the leading phase angle of the power versus the water level of the tank, clearly illustrating that the phase angle increases to a higher value at unloaded tank conditions, decreases to a lower value at an early liquid level, and then remains substantially constant. This again is in contradistinction with the heretofore known cleaning systems where the power goes through extreme swings as the water level of the tank changes, i.e. goes through quarter wavelengths of the resonant frequency.

FIGURE 7 shows the electrical admittance versus water level. The curve **48** illustrates that the electrical admittance of the oscillatory circuit remains substantially constant with changing water levels, which feature makes it possible to connect several cleaning tanks having different water levels in parallel, a feature not possible heretofore.

In a typical case it was possible to operate four to seven transducers in parallel without retuning. Also, three separate tanks which totalled six transducers were run successfully from a single generator.

Other typical operating conditions tested have been as follows:

Quantity of Transducer Elements* Affixed to Tank 12	Current Arms		Value of Capacitor (22), mfd.	Value of Inductance (20), mh.	Frequency f_o, kHz.
	I_i	I_o			
6	3.3	1.5	0.03	0.15–0.18	43.5
12	4.35	3.0	0.05	0.09–0.10	43.5

*Static capacitance approx. 0.0055 mfd. per transducer element.
Windings 24*a* and 24*aa*—40 turns each.
Windings 24*b* and 24*c*—20 turns each.

It will be apparent that the value of capacitor **22** may be decreased by using a consequent increase in the number of turns in the winding **24***a*, the only condition being that an increase in current in the value of I_0 produces a decrease of the value of I_f.

It has been found that a further improvement can be made by using a modification as indicated in FIGURE 8. The remaining ripple in the power of the oscillatory circuit as a function of water level and loading evident in FIGURE 6 can be smoothed still further by modulating the high frequency of the oscillatory circuit with a lower frequency signal. A typical arrangement of this kind is shown in FIGURE 8 wherein the transformer **24** has been provided with a further set of secondary control windings **24***e* and **24***d* which are arranged in opposition. These windings are energized via a resistor **38**, typically, with a 120-cycle pulsating unidirectional current signal to cyclically shift the magnetization and flux of the transformer core. The overall effect of this low frequency sweep results in a periodic frequency excursion Δf of the oscillatory circuit from the point f_0 shown in FIGURE 5. The 120-cycle pulsating unidirectional signal is merely illustrative of a lower frequency modulating signal which may be used and which can readily be derived from a full wave rectifier connected to a 60-cycle power line. Instead of superimposing the low frequency signal upon the oscillatory circuit at the transformer **24**, it may be applied to the circuit at other points without deviating from the principle described.

The above described arrangement, therefore, discloses an ultrasonic cleaning system which: (a) permits several tanks to be connected in parallel, (b) provides for substantially constant power level despite variations in liquid level and load, (c) provides for a reduction in power supplied to the transducer as the tank approaches zero liquid level, (d) eliminates extreme power fluctuations caused by changing loads, and (e) obviates the need for manual or automatic means to maintain the oscillatory circuit at the critical point of resonance. All of these features are achieved with a rather simple circuit arrangement, characterized by a minimum number of components.

Although a preferred embodiment of the invention has been described in detail and certain modifications and variations have been indicated, it is to be understood that this invention is not limited to this preicse embodiment, and that various other changes and modifications may be effected therein without departing from the scope or spirit of the invention.

What is claimed is:

1. In an apparatus for driving a load circuit which includes an ultrasonic transducer having a natural frequency of vibration and exhibiting a reactance, the combination of:

an oscillatory circuit comprising a reactance connected in series with said transducer, said oscillatory circuit being tuned to a frequency which is higher than the antiresonance frequency of said transducer;

means coupled in circuit with said transducer for providing a control signal which decreases in amplitude as the current through said transducer increases caused by resonance load conditions;

a driving circuit, which includes a source of electrical energy and a switching means, coupled to said oscillatory circuit, and

means coupling said control signal as a feedback signal to said switching means for controlling the operation of said driving circuit, whereby to sustain operation of said oscillatory circuit.

2. In an apparatus as set forth in claim **1** wherein said transducer exhibits a capacitive reactance and said reactance connected in series with said transducer is an inductance.

3. In an apparatus for driving a load circuit which includes an ultrasonic transducer having a natural frequency of vibration and exhibiting a capacitive reactance, the combination of:

an oscillatory circuit comprising an inductance connected in series with the parallel connection of a capacitor and said transducer, said oscillatory circuit being tuned to a frequency which is higher than the antiresonance frequency of said transducer;

summing means coupled in circuit between said transducer and said capacitor for subtracting a first signal responsive to the current through said transducer from a second signal responsive to the current through said capacitor, said capacitor and summing means being selected to cause said second signal to be larger than said first signal, whereby to provide a difference signal which decreases in amplitude as the current through said transducer increases;

a driving circuit, which includes a source of electrical energy and a switching means, coupled to said oscillatory circuit, and

means coupling the difference signal from said summing means as a feedback signal to said switching means for controlling the operation of said driving circuit, whereby to sustain operation of said oscillatory circuit.

4. In an apparatus for driving a load circuit as set forth in claim **3**, said summing means comprising a transformer.

5. In an apparatus for driving a load circuit as set forth in claim **3**, said summing means comprising a transformer having two primary windings, one winding connected in series with the current through said transducer and the other winding connected in series with the current through said capacitor and a secondary winding for providing the difference signal.

6. In an apparatus for driving a load circuit as set forth in claim **3**, said capacitor having a capacitance which is larger than that of said transducer.

7. In an apparatus as set forth in claim **3** wherein said source of electrical energy is a direct current supply and said switching means is a transistor serially connected in circuit therewith.

8. In an ultrasonic cleaning apparatus comprising:

(A) a tank adapted to hold a liquid and having piezoelectric ultrasonic transducer means for providing, when energized, sonic energy to the liquid contained in said tank;

(B) a generator coupled to said transducer means for driving said transducer means with high frequency electrical energy, said generator including:

(B1) an oscillatory circuit tuned to a frequency which is above that of antiresonance of said transducer means having an inductance serially coupled in circuit with the parallel connection comprising said transducer means and a capacitor; said transducer means and capacitor being connected to each other by an electrical summing means for subtracting the current through said transducer means from the current flowing through said capacitor, said capacitor and summing means being selected to cause a difference signal which decreases in amplitude as the current through said transducer means increases;

(B2) a driving circuit including a transformer having a primary winding and a secondary winding coupled to said oscillatory circuit, said secondary winding coupled to said inductance and said summing means, and said primary winding being coupled in series with a switching means to a source of direct current, and

(B3) a feedback circuit which includes means for coupling said difference signal to said switching means for causing said switching means to periodically provide pulses of energy from said source to said primary winding in phase with the oscillations of said oscillatory circuit whereby to sustain operation of said oscillatory circuit at the above-antiresonance frequency.

9. In an ultrasonic cleaning apparatus as set forth in claim **8** wherein said summing means comprises a center tapped primary winding on a further transformer, and said feedback circuit includes a first secondary winding on said further transformer for developing said difference signal.

10. In an ultrasonic cleaning apparatus as set forth in claim **9** wherein said further transformer includes a secondary winding connected in series with a rectifier and an electrical resistance in order to reflect a load into said oscillatory circuit during the one-half cycle when said switching means is not providing pulses of energy.

11. In an ultrasonic cleaning apparatus as set forth in claim **10** wherein said further transformer includes a third secondary winding which is energized with pulsating unidirectional current having a fundamental frequency substantially lower than that of the oscillatory circuit.

12. In an ultrasonic cleaning apparatus as set forth in claim **8** wherein said switching means is a transistor and said difference signal is coupled as a control signal to said transistor to control the flow of electrical energy therethrough from said source of direct current to said primary winding.

13. In an apparatus for driving a load circuit which includes an ultrasonic transducer having a natural frequency of vibration and exhibiting a reactance, the combination of:

an oscillatory circuit comprising a reactance connected in series with said transducer, said oscillatory circuit being tuned to a frequency which is higher than the antiresonance frequency of said transducer;

means coupled in circuit with said transducer for providing a control signal responsive to the amplitude of the current through said transducer;

a driving circuit, which includes a source of electrical energy and a switching means, coupled to said oscillatory circuit, and

means coupling said control signal as a feedback signal to said switching means for controlling the operation of said driving circuit and for causing said circuit to oscillate at a frequency detuned from the condition of maximum circuit admittance caused by resonance load condition effective upon said transducer.

14. In an apparatus as set forth in claim **13** wherein said transducer exhibits a capacitive reactance, said reactance connected in series with said transducer is an inductance, and said control signal decreases in amplitude as the current through said transducer increases.

15. An ultrasonic cleaning apparatus comprising in combination:

a power supply;

an oscillatory circuit coupled for being driven by said power supply;

a piezoelectric transducer designed for operation in the ultrasonic frequency range forming a part of said oscillatory circuit and adapted to be coupled to a load which includes a liquid confined in a tank for providing acoustic energy in the ultrasonic frequency range to the liquid;

control means which include a capacitor coupled through a summing means in parallel with said transducer, said summing means providing a control signal which is the difference between the current through said capacitor and that through said transducer and which decreases in amplitude responsive to increasing current through said transducer;

means causing said control signal to be connected as a feedback signal to a means controlling the flow of current from said power supply to said oscillatory circuit whereby to sustain the oscillations of said oscillatory circuit, and

said oscillatory circuit being arranged to operate at a frequency which is at least as high as the antiresonance frequency of said transducer.

16. An ultrasonic cleaning apparatus as set forth in claim **15**, said capacitor being selected to cause the current therethrough to exceed that through said piezoelectric transducer.

17. An ultrasonic cleaning apparatus comprising in combination:

an electrical power supply;

an oscillatory circuit coupled for receiving electrical energy from said power supply;

a piezoelectric transducer, designed for operation in the ultrasonic frequency range, forming a part of said oscillatory circuit coupled for receiving electrical energy and providing acoustic energy in the ultrasonic frequency range to a body of liquid confined in a tank;

feedback means coupled between said oscillatory circuit and said power supply for controlling the flow of power from said supply to sustain the oscillations of said oscillatory circuit, and

electrical circuit means coupled in circuit with said transducer for causing said oscillatory circuit to oscillate at a frequency which is higher than the antiresonance frequency of said transducer.

18. An oscillatory circuit for an ultrasonic cleaning apparatus comprising in combination:

a transformer having a primary and a second winding;

a supply of direct current coupled in series with a switching means across said primary winding;

said secondary winding having its terminals coupled respectively to one side of an inductance and to the center tap of a primary winding of a second transformer;

the other side of said inductance being coupled respectively to one input terminal of a capacitor and that of a piezoelectric transducer, the latter being adapted to provide acoustic energy to a liquid when energized with electrical energy;

the other terminal of said capacitor and that of said piezoelectric transducer being coupled to the respective terminals of said primary winding of said second transformer;

a secondary winding disposed on said second transformer for producing a signal which is responsive to the difference of the current flowing through said capacitor and the current through said transducer;

means coupling said signal as a feedback signal to said switching means to sustain the oscillations of said oscillatory circuit, and

said inductance and said capacitor being selected to cause said oscillatory circuit to operate at a frequency which is above the antiresonance frequency of said transducer, and said capacitor being selected to cause the current therethrough to exceed that through said transducer.

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MILTON O. HIRSHFIELD, Primary Examiner

M. O. BUDD, Assistant Examiner

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,500,089 Dated March 10, 1970

Inventor(s) Kilian H. Brech et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 57 "ultransonic" should read --ultrasonic--; Column 3, line 13 "ultransonic" should read --ultrasonic--; Column 3, line 37 "f_o" should read --f_o'--;

Claim 10, column 7, line 69 after "includes a" insert --second--; Claim 13, column 8, line 29 "condition" should read --conditions--.

SIGNED AND
SEALED
AUG 18 1970

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents