MULTIFREQUENCY ULTRASONIC CLEANING EQUIPMENT

Filed June 28, 1965

3 Sheets-Sheet 1

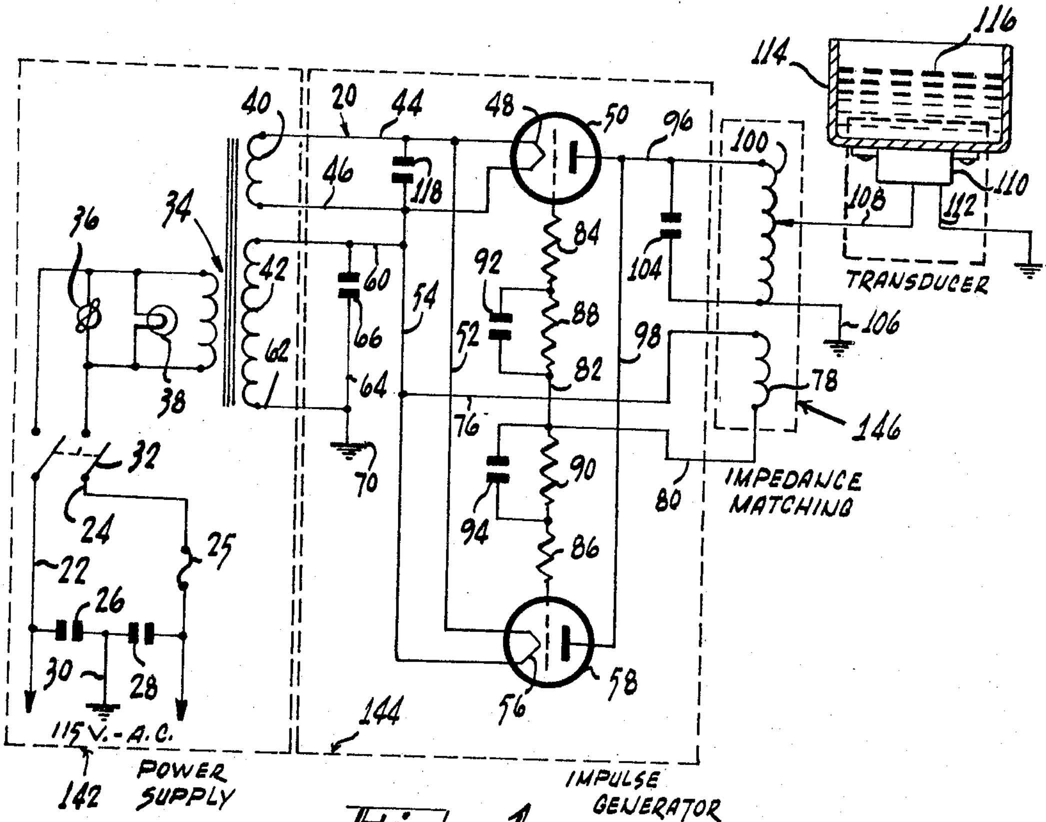

Fig. 1

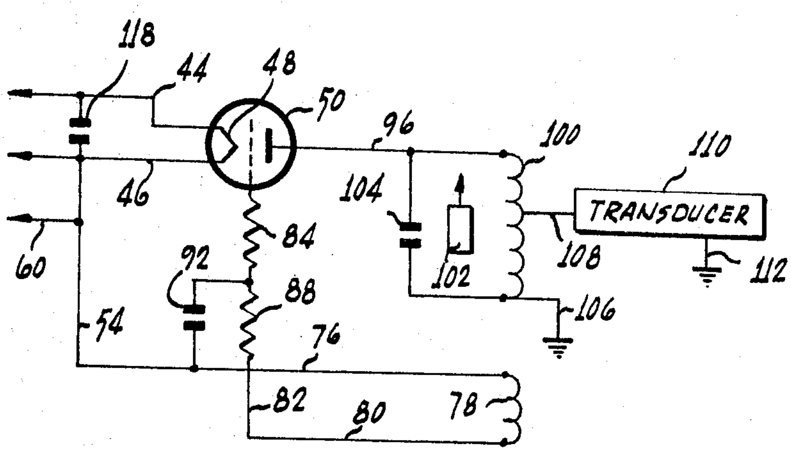

Fig. 2

INVENTOR
EDWARD G. COOK
BY Albert Sperry
ATTORNEY

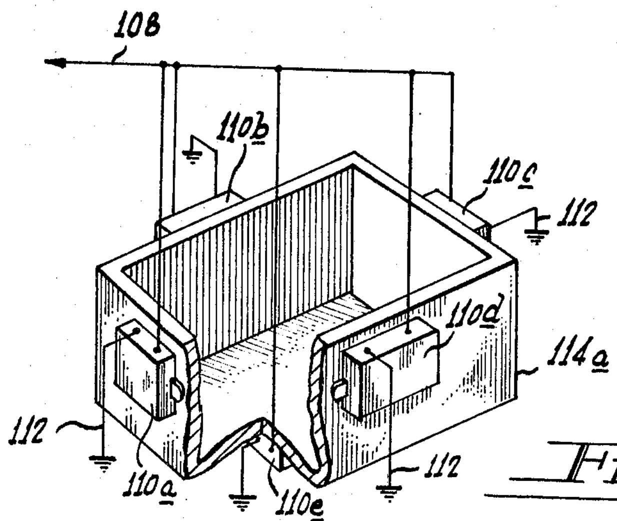

FIG. 3

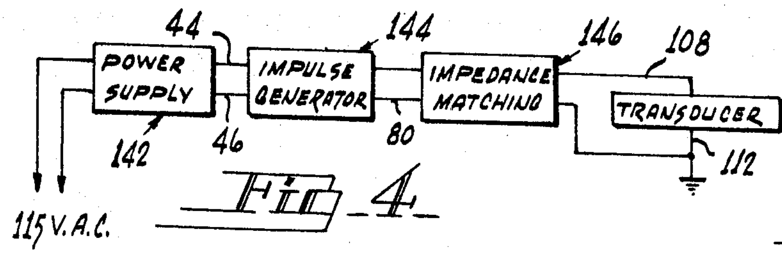

FIG. 4

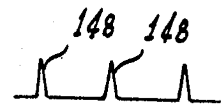

FIG. 5

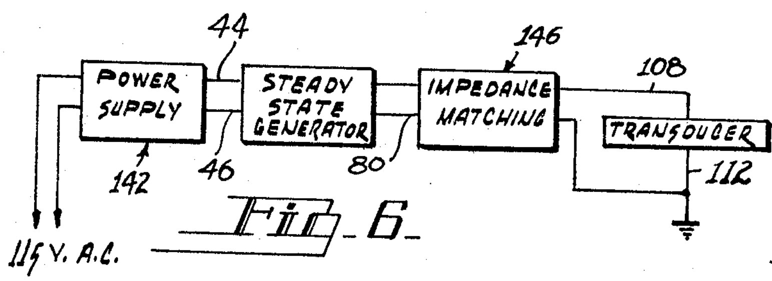

FIG. 6

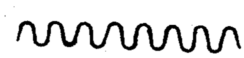

FIG. 7

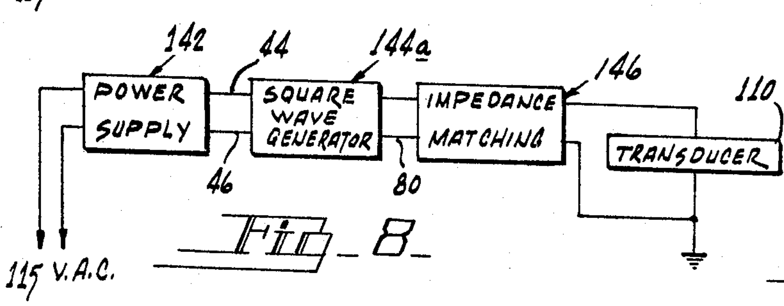

FIG. 8

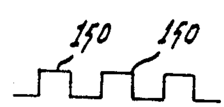

FIG. 9

INVENTOR
EDWARD G. COOK
BY Albert Sperry
ATTORNEY

MULTIFREQUENCY ULTRASONIC CLEANING EQUIPMENT

Filed June 28, 1965 3 Sheets-Sheet 3

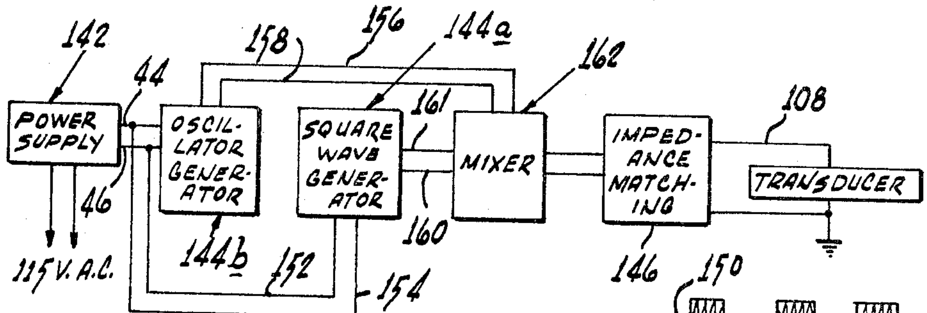

Fig. 10

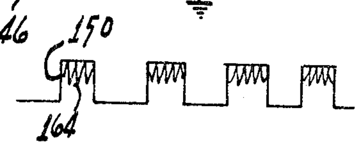

Fig. 11

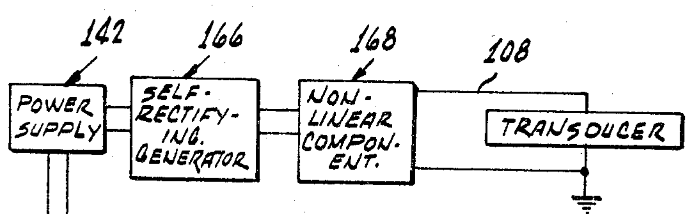

Fig. 12

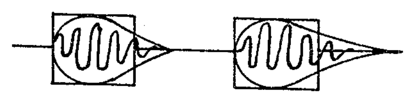

Fig. 13

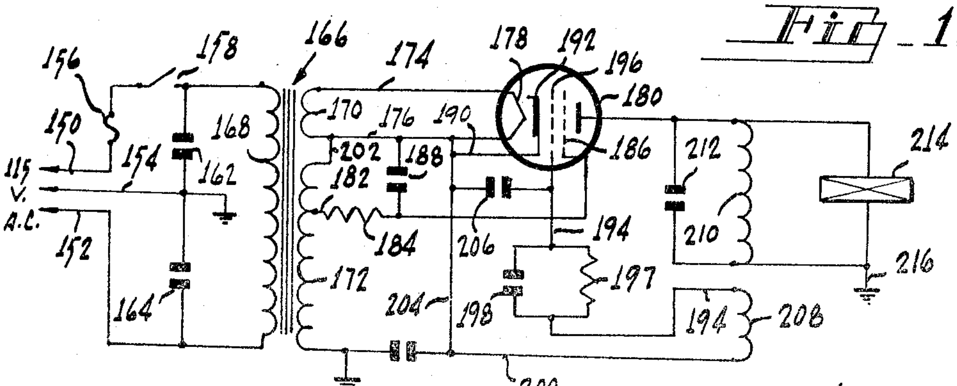

Fig. 14

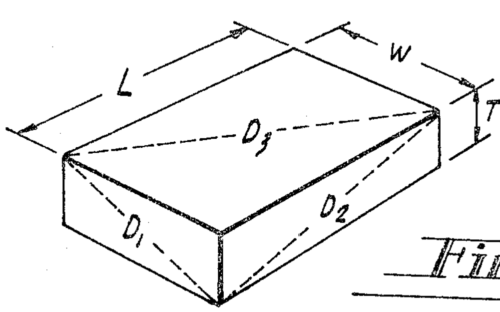

Fig. 15

INVENTOR
EDWARD G. COOK
BY Albert Sperry
ATTORNEY

United States Patent Office

3,371,233

Patented Feb. 27, 1968

1

3,371,233

MULTIFREQUENCY ULTRASONIC CLEANING EQUIPMENT

Edward G. Cook, 9 Richie Lane, Yardley, Pa. 19067

Filed June 28, 1965, Ser. No. 467,319
3 Claims. (Cl. 310—8.1)

ABSTRACT OF THE DISCLOSURE

A transducer is attached to a cleaning tank and is of a shape incorporating in it a plurality of differing dimensions. In each dimension, the transducer resonates in a plurality of differing fundamental modes and their harmonics. By shock excitation, there is simultaneously applied to the transducer a multitude of frequencies falling within a range encompassing the fundamental vibratory modes and the harmonics thereof in which the transducer is known to be resonant in each of its several dimensions. This in turn generates simultaneously within the tank a wide band of frequencies to improve the cleaning of an immersed article.

This invention relates to ultrasonic cleaning devices of the type wherein an article to be cleaned is immersed in a liquid, to be subjected therein to ultrasonic wave energy transmitted through the liquid by one or more transducers.

Ordinarily, ultrasonic cleaning apparatus of the character described utilizes a single-frequency transducer system, or a slight variation about a single frequency. In this connection, while the advantages of ultrasonic cleaning are many, even when a single frequency system is employed, there is nevertheless a basic deficiency in such a system. This deficiency has prevented ultrasonic cleaning from attaining its maximum capability as regards cleaning of articles having a wide variety of component portions differing in configuration or dimension from one another.

The disadvantage inherent in single-frequency ultrasonic cleaning systems springs directly from the fact that such a system produces a standing wave pattern within the tank. This results from the fact that in a single-frequency ultrasonic cleaning system, there is steady state excitation, productive of a continuous, unchanging, symmetrical wave form reflecting in a correspondingly unchanging manner from the sides and bottom of the cleaning tank. In such an arrangement, the peaks and nulls of the wave occur, in a given cleaning cycle, at certain levels or areas of the cleaning area of the tank and remain in said areas throughout the cycle.

Since the ultrasonic energy that produces the cleaning action varies in proportion to the peaks and nulls of the waves, a standing wave pattern derived from generation of a single-frequency results in a cleaning action which, though reasonably efficient, has certain basic deficiencies. It is known, in this regard, that in the higher frequency range there is a penetration of small crevices, and a loosening of the contaminates found therein. In the lower frequency range, on the other hand, larger, more open areas are cleaned with particular effectiveness. It follows that in the standing wave pattern of a single frequency system, there is a loss of efficiency due to the fact that the frequency used may be well suited for cleaning some parts of the workpiece, but not others. The loss of efficiency is heightened by the peak-and-null characteristic as a factor in the cleaning action.

Most desirably, there should be simultaneous generation of a wide band of ultrasonic cleaning frequencies, occurring anywhere and everywhere, so to speak, within

2

the cleaning tank. As will be appreciated from the discussion provided hereinbefore, an ultrasonic cleaning system having this characteristic has the decided advantage that in all areas of the tank, higher frequencies will generate tiny cavitation bubbles that will penetrate into correspondingly small crevices or orifices, in such a fashion as to loosen contaminates therein. The lower frequencies, with their larger cavitation bubbles and greater cleaning power, can then rapidly and thoroughly complete the cleaning operation in the same area. It will be noted, in this regard, that in a simultaneous multi-frequency system of this type, there would still be standing wave patterns. They would, however, be offset from one another spatially. Thus, if for example there are six frequencies present simultaneously, there will be six times as many peaks and nulls as there would be in a single frequency system, plus an infinite number of harmonics of each.

Among more particular objects of the invention are the following:

First, to obtain a form of automatic tuning of the transducer or transducers, responsive simply and entirely to shock-excitation of the transducers in their various fundamental modes;

Second, to eliminate the need (presently found in single frequency systems) of critical matching of transducers;

Third, to screen out undesirable noise, as distinguished from single-frequency systems, which are often productive of almost unbearable noises by reason of the tendency of such systems to get into audible frequencies;

Fourth, to eliminate the effects of different liquid levels, liquid temperatures, types of liquid, chemicals used in the cleaning liquid, and the form and volume of the workpieces being cleaned, as regards efficient resonation of the transducers; and

Fifth, to provide equipment as described that will be rugged, will include comparatively simple but effective circuitry for resonating the transducers in a manner to produce simultaneously a multiplicity of frequencies, and will be designed for minimum maintenance and repair.

Toward the accomplishment of the above stated objects, I have devised an ultrasonic cleaning apparatus of the type wherein an object is immersed in a cleaning liquid through which ultrasonic wave energy is transmitted by one or more transducers. The invention, summarized briefly, makes use of a rectangular transducer, which will reasonate at many more frequencies than will a circular transducer. In combination with such transducer, I provide a pulsing circuit so designed as to effect shock-excitation of the transducer or transducers, in random fashion. The result is that each transducer will resonate in all of its frequencies, plus harmonics thereof, thus to generate simultaneously, within the cleaning tank, a wide band of ultrasonic cleaning frequencies. In accordance with the invention, the output of the novel generator circuit which I have devised consists of a pure, impulse excitation, or a square wave excitation with steady state superimposed. The nature of the generator circuit is such as to make it unnecessary to have the selected wave form or forms tuned to the resonant frequency of the transducers. In fact, advantage is taken of combining as many frequency components as possible in the output wave form, with the transducers themselves providing the frequency governing elements.

Other objects will appear from the following description, the claims appended thereto, and from the annexed drawings, in which like reference characters designate like parts throughout the several views, and wherein:

FIG. 1 is a largely diagrammatic showing of one form of generator circuit according to the present invention, in association with a cleaning tank and transducer;

FIG. 2 is a fragmentary, schematic view of a modified generator circuit;

FIG. 3 is a perspective view, somewhat diagrammatic, of a modified cleaning tank usable with any of the circuits shown in FIGS. 1–4, a portion of the tank being broken away;

FIG. 4 is a block diagram illustrative of the circuit shown in FIG. 1;

FIG. 5 is a view showing the wave form produced by the FIG. 4 circuitry;

FIG. 6 is a block diagram of a circuit designed to produce a steady state wave form;

FIG. 7 is a view showing the wave form produced by the circuit of FIG. 6;

FIG. 8 is a block diagram showing a circuit for producing a square wave form;

FIG. 9 is a view showing the wave form produced by the circuit of FIG. 8;

FIG. 10 is a block diagram showing another circuit arrangement, for producing a modulated wave form comprising a square wave with a steady state wave form superimposed thereon;

FIG. 12 is a block diagram of a circuit for producing an alternative modulated wave form of the type wherein a steady state wave form is superimposed on a square wave;

FIG. 13 is a view of the wave form produced by the circuit of FIG. 12;

FIG. 14 is a diagram of another circuit adapted to produce a multiplicity of frequencies simultaneously; and

FIG. 15 is a somewhat diagrammatic view of a transducer embodied in the invention, showing the six fundamental modes in which random excitation of the transducer occurs for creating the multi-frequency characteristic of the invention.

Referring to the drawing in detail, in FIG. 1, I have illustrated one circuit advantageously employed for the purpose of random shock-excitation of one or more transducers to produce the simultaneous multifrequency characteristic hereinbefore discussed. The circuit comprises, in its basic essentials, a power supply, an impulse generator, impedance matching, and one or more transducers, and FIGURE 1 has been appropriately divided to show which portions of the circuitry illustrated therein constitute these components.

The ultrasonic generator circuit shown in FIG. 1 is thus a means for exciting a transducer in a manner effective to produce simultaneous vibrations thereof in a multiplicity of differing fundamental modes and their harmonics. The circuit **20** devised for this purpose includes leads **22, 24** extending from opposite sides of a conventional 115 v. AC, three-wire power supply having a ground connection. One side of the circuit is fused as at **25**.

Capacitors **26, 28** are interposed between a connection **30** extending to the ground wire of the AC power supply, and the respective leads or sides **22, 24** of said power supply. Also provided is a double-pole switch **32** manually operable as a main on-off switch of the circuit, and designed to break both sides of the circuit simultaneously.

Leads **22, 24** are connected to the opposite terminals of the primary winding of a power transformer **34**. Connected in parallel across the leads **22, 24** between switch **32** and the primary winding of the transformer, in a cooling fan **36**, and a pilot light **38**.

The power transformer has a low voltage secondary winding **40**, and a higher voltage secondary winding **42**. From the opposite terminals of the low voltage winding extend leads **44, 46**. These leads extend to the filament **48** of a first amplifying triode **50**.

By means of leads **52, 54** connected to leads **44, 46** respectively, power is also supplied to the filament **56** of a second amplifying triode **58**.

From the opposite terminals of the secondary winding **42**, extend leads **60, 62**. A lead **64** is connected and extends from the lead **60**, a capacitor **66** being connected in the lead **64**. Lead **64** is connected to ground as at **70**.

A lead **76** extends from the lead **54**, to one terminal of a low voltage coil **78**, from the other terminal of which extends a lead **80**. The lead **80** extends to a connection with a lead **82**, that provides a line of transmission of electrical energy from lead **80** to the control grids of the triodes **50, 58** respectively. Identical circuitry is employed between the juncture of leads **80, 82**, and the respective control grids of the vacuum tubes. Thus, connected to the control grids are resistors **84, 86**. In series with the resistors are resistors **88, 90** respectively. Capacitors **92, 94** are connected in shunt across the resistors **88, 90** respectively.

Extending from the plate of triode **50** is a lead **96**. A lead **98** extends from the plate of the triode **58**, to a connection with the lead **96**, so that the combined output of both triodes is then transmitted through lead **96** to one terminal of an impedance matching output coil **100**.

In shunt across the coil **100** is a capacitor **104**. A ground connection **106** is then provided, connected to the other terminal of the coil **100** to provide a means for return of the electrical energy supplied to the coil, back to the source of power.

Extending from the impedance matching coil **100** is a lead **108**, through which impulses emanating from the coil are transmitted to a transducer **110**. A return to the power source is provided for the transducer, through the provision of a ground connection **112**.

In FIG. 1, the transducer is shown secured to the bottom of a cleaning tank **114**, having therein a cleaning liquid **116** in which an article to be cleaned, not shown, is immersed. The liquid **116** is preferably maintained at a temperature of about 140° F.

The transducer **110** is, in a preferred embodiment of the invention, of rectangular configuration, and is designed, when driven by a generator circuit as illustrated and described, to provide, simultaneously, a wide band of ultrasonic cleaning frequencies within the cleaning tank. The transducer vibrates in a plurality of fundamental modes simultaneously, plus all of the harmonics.

Reference should be had, in this regard, to FIG. 15. The transducer there shown includes six fundamental dimensions or modes, namely its width, W; thickness, T; length, L; transverse or width diagonal, D_1; thickness diagonal, D_2; and longitudinal diagonal, D_3.

These characteristics of the transducer are productive of six fundamental resonances. Thus, let it be assumed that

λ_1=wavelength of the dimension W,
v_1=velocity of sound in the dimension W, and
f_1=the resonant frequency of said dimension W.

In these circumstances, it can be considered that

$$W=\frac{v_1}{2f_1}$$

And, with respect to the longitudinal dimension, it can be concluded that

$$L=\frac{v_2}{2f_2}$$

And, as to the width dimension,

$$T=\frac{v_3}{2f_3}$$

This calculation would be carried on similarly, as will be understood, through the D_1, D_2, and D_3 dimensions.

If desired, a steady state frequency can be superimposed upon those described above. If so, it would be selected, preferably, from one close to the thickness mode. The thickness mode would be driven twice, once by the steady state impulse and once by random shock excitation.

It is of interest to note that in actual practice, what the frequency of the thickness mode will be is governed in large degree by the piece of piezoelectric ceramic material used in the transducer.

The actual thickness resonant frequency is determined by the characteristics of the ceramic which is the piezoelectric element and the thickness of the metal transducer bar. I have discovered by experiment that certain classes of ceramics, such as barium titanate and lead zirconium titanate, have the property that there is more than one fundamental thickness mode. These modes are spaced only four or five kc. apart; this, when combined with the metal bar of the transducer, would produce thickness modes at 30 kc. and 34 kc. By proper adjustment of the circuit one can have the transducer actually vibrating at both of these modes simultaneously. Thus, not only does one have the thickness mode, plus the five other modes of the transducer, but also the other thickness mode governed by the subsidiary modes of the ceramic element itself. These subsidiary modes may range in number from one to perhaps three or four. Therefore, in reality, assuming that the ceramic has just one of these subsidiary modes, one could have two entirely different families of simultaneous multi-frequency. One family would be the 20, 30, 40, 60, 80, and 90 kc. corresponding to the 30 kc. thickness mode of the ceramic. The other family would be a similar series of frequencies where all of their resonant frequencies would be increased by 4 kc. which corresponds to the 4 kc. increase in the first subsidiary of the ceramic. In other words, the second resonance of the ceramic would provide a transducer thickness resonance of 34 kc. Also, it would give a series of resonances at 24 kc., 44 kc., 64 kc., 84 kc. and 94 kc. Obviously, all of these frequencies are approximate.

It follows that there could be other subsidiary modes in the piezoelectric ceramic which give rise to further series of resonant frequencies in the transducer bar. The circuit is adjusted such that the transducer has both of these modes and their families of fundamental resonances going at once. Or, the circuit can be adjusted to alternately flip-flop back and forth between these multiple modes.

When all these operational characteristics are considered in their cumulative effect, a multiplicity of frequencies occur within the tank, going in all directions to produce a highly desirable uniformity of cleaning action throughout the entire tank volume. This results from the fact that higher frequencies present throughout said tank volume generate minute cavitation bubbles, that penetrate small crevices, capillaries, orifices, etc., so as to loosen contaminates found therein. Meanwhile, a considerable range of lower frequencies will also be found to be present throughout the tank volume, and these, having larger cavitation bubbles and greater cleaning power, complete the removal of the contaminates, so as to rapidly and thoroughly clean the immersed article in a uniform fashion, despite the shape of the article itself, or the dimensions, size, and configuration of any component portion thereof.

This characteristic obtains by reason of the fact that the generator circuit illustrated and described tends to randomly shock-excite the transducer. It is important to note, in this regard, that it is not necessary to have the wave form of the generator output tuned to the resonant frequency of the transducer. Rather, in effect, automatic tuning is obtained, because the transducer is not driven at resonance and will vibrate at its own fundamental frequencies together with the harmonics thereof. At the same time, as described above, a steady state wave form can be superimposed, whose frequency is determined by thickness of the transducer.

The transducers employed in carrying out the invention preferably are high efficiency transducers employing a new class of special high temperature titanate alloys which overcome previously observed difficulties of low transducer efficiency and poor reliability. With the new transducers it is possible to obtain high efficiency with proven reliability and ruggedness. These transducers can operate at temperatures in the range of the boiling point of water, and can be operated continuously twenty-four hours a day, seven days a week.

Historically, the conventional single-frequency magnetostrictive transducers have been used for production systems and have had the desired reliability, but have been seriously handicapped by their low efficiency. Conventional barium titanate transducers were developed with the required increased efficiency, but were found not to have the required reliability under production usage.

The transducer **110**, by reason of its special design, combines the ruggedness of the magnetostriction with the increased efficiency of the old style titanates, and additionally, aids measurably in the simultaneous generation of many frequencies within the cleaning tank. The transducer, as above noted, is rectangular in form, and by virtue of its design and construction has a variety of fundamental resonant frequencies. This is similar to a rectangular drumhead which, when struck in the center, will vibrate in more than one resonant frequency governed by its width, length, and diagonals. It is for this reason that when the transducer is randomly excited, it vibrates in its various fundamental frequencies, plus their harmonics, all of which combine to provide the highest possible cleaning energy within the tank.

Referring now to FIG. 2, there is here illustrated a fragmentary portion of a modified generator circuit of lower output. In this connection, the circuit shown in FIG. 1 has an output on the order of about 200 watts. This results from the cumulative action of the two amplifying circuits including tubes **50**, **58**, each of which produces approximately 100 watts.

Thus, in FIG. 2 the output is halved, since the tube **58**, together with resistors **86**, **90**, and capacitor **94** arranged in combination therewith as shown in FIG. 1, is omitted. In the generator circuit shown in FIG. 2, lead **80** has a connection only to the control grid of the single tube **50** employed in the FIG. 2 circuit.

The output of the circuit shown in FIG. 2, thus, is on the order of about 100 watts.

Connected across the leads **44**, **46**, is the capacitor **118**.

FIG. 3 illustrates, somewhat diagrammatically, a modified cleaning tank **114***a*. This tank includes transducers mounted upon the respective side walls thereof. The transducers have been designated **110***a*, **110***b*, **110***c*, and **110***d*, and they are all similar to one another in the illustrated example, although this is not at all essential to successful use of the invention. Also provided is a transducer **110***e* on the bottom wall. As will be noted, the transducers are connected in parallel to the lead **108** supplying the pulsing currents thereto. Therefore, a modular arrangement is possible, wherein any transducer can be cut out of the circuit, without adverse effect upon the remaining transducers. This is advantageous in the event of the necessity of repair or replacement of one or more of the transducers. Cleaning operation can continue with those that remain in working order.

When a plurality of transducers is used, there is no necessity of critical matching of the same. This is so because each transducer, as described above, is resonated at its own frequency, by random pulses producing shock-excitation. In this way, I eliminate any difficulties arising from the necessity of closely matching each transducer to the other, or in keeping the system in tune to a specific frequency.

By reason of the parallel connection of the several transducers, promoting a modular system, it is possible to provide cleaning tanks of any desired size, since one need only add transducers in parallel connection as necessary, together with additional generator circuits as required by the power demands of the transducers. The modules thus provided can cooperate in the cleaning of a single large article, in a tank of any size, or alternatively, can be used to provide for side-by-side cleaning of a plurality of work pieces simultaneously, in a partitioned tank or in adjacent, separate tanks.

In FIG. 4, I have shown a block diagram of the basic circuitry shown in FIG. 1. As will be noted, a simple circuit is provided, wherein the power supply or input circuit **142** comprises that part of the circuitry of FIG. 1 extending from the 115 v. AC source to and including power transformer **34**. Leads **44, 46** extend to the impulse generator circuit **144**. This comprises the vacuum tubes **50** and **58**, together with the coil **100** and coil **78**.

Generally designated **146** is an impedance matching circuit, including a feedback circuit containing coil **78**. Coil **78** serves to adjust the control grids of tubes **50, 58**. The coil **78** of the feedback circuit is connected to the impulse generator circuit **144** by the lead **80**.

Also as shown in FIG. 4, the transducer **110** (or transducers, should a multiple transducer arrangement be used as in FIG. 3) is supplied with pulsating current through the lead **108**. This produces, considering the circuit of FIG. 1, a wave form transmitted to the transducer through lead **108**, having characteristics as shown in FIG. 5. As will be noted, the wave form includes spikes **148** occurring on the occasion of each shock-excitation. These effectively produce the random excitation of the transducer or transducers, to cause the same to resonate in their own frequencies.

In FIG. 6, I show by block diagram the provision of a steady state generator producing a wave form having the appearance shown in FIG. 7. This has been included to show the adaptability of the basic circuitry, hereinbefore described, to include a generator of this type, either alone or (as will later appear) in combination with other types of generators.

In FIG. 8, I have illustrated by block diagram a modification in the generator circuit, designed to produce a square wave as shown in FIG. 9. This produces a variation in the multifrequency action, while still retaining the basic concept of the invention, that is, the resonation of the transducers in their own fundamental modes and harmonics thereof, to produce multifrequencies traveling throughout the tank to all areas thereof.

FIG. 8 shows a circuit identical to that shown in FIG. 4, except that the generator circuit **144*a*** is designed for production of a square wave.

The square wave, illustrated in FIG. 9, includes a wave form **150** wherein there is a sharp rise followed by a relatively short plateau followed by a sharp descent to the base level of the wave form.

In FIG. 10, I show a block diagram of a circuit adapted to produce a modulated wave form. In this circuit arrangement, two different types of pulse-generating circuits are, in effect, connected in parallel, with the combined output of the circuits being directed to a mixer for transmission to a transducer.

Thus, extending from the power supply **142** are the leads **44, 46**. These extend to an oscillator generator circuit **144*b***, designed to produce a steady state wave form.

The square wave generator circuit **144*a*** previously described is also supplied with power from the power supply circuit **142**, through the medium of leads **152, 154** extending from the leads **44, 46** respectively.

Leads **156, 158** extend from the circuit **144*b***. Leads **160, 161** extend from the circuit **144*a***, to a mixer generally designated **162**. Leads **156, 158** extend to the mixer, in which the pulses emanating from the two generator circuits are intermixed for transmission through lead **108** to the transducer.

This produces a modulated wave form as in FIG. 11. The square wave generator circuit **144*a*** provides the square wave form **150**, as shown in FIG. 9. Within each square wave, however, there is provided a steady state wave form **164**, thus producing the desired modulation of the wave form.

Another circuit can be utilized, and is shown in FIG. 12. In this arrangement, there is a self-rectifying generator **166**, connected to the usual power supply. Leads extend from the generator **166** to a non-linear component generally designated **168**, having the connection **108** extending to the transducer. This produces a wave form as in FIG. 13.

FIG. 14 shows yet another circuit that has proved effective. This includes power leads **150, 152** and ground connection **154** of a 115 v. AC current supply. Fuse **156** and normally open, manually operated main control switch **158** are connected in one side of the circuit. Across the power leads is a connecting lead **160** having in series the capacitors **162, 164**. Transformer **166** has a primary **168**, a low voltage secondary **170**, and a higher voltage secondary **172**. Leads **174, 176** extend from secondary winding **170** to the heater **178** of a pentode **180**.

Lead **182** extending from an intermediate area of winding **172** has connected therein a resistor **184**, and is connected to the suppressor **186** of the pentode. Connected across leads **176, 182** is a capacitor **188**.

A connection **190** extends from lead **176** to the cathode **192** of the pentode. Lead **194** extends between grid **196** of the pentode and is provided with resistor **197** having in shunt thereacross a capacitor **198**.

Leads **200, 202** extend from the respective ends of secondary **172**. Connected between leads **190, 200** is a lead **204**. A capacitor **206** is connected between leads **204, 194**.

Leads **194, 200** are connected to the respective ends of low voltage coil **208** of an impedance matching means. Said means is provided also with an impedance matching coil **210** having in shunt thereacross a capacitor **212**. A transducer **214** receives the output of the impedance matching coil **210** in the same manner as has been described with reference to the FIG. 1 circuit, and has a ground connection **216**. The circuit may in some instances be used without capacitor **212**. Therefore, although I have illustrated the capacitor **212** as part of the circuit, I may or may not use it in actual practice.

In practice, an ultrasonic cleaning apparatus formed as described herein has been found to produce a highly desirable improvement in the cleaning action of workpieces, regardless of the shape, size, or complexity of said workpieces. As previously noted herein, the circuitry illustrated and described has the desirable effect of promoting a multiplicity of frequencies, resulting from random shock-excitation of the transducer or transducers, whereby automatic tuning is produced, without requirement of critical matching of the transducers in any way.

It is believed apparent that the invention is no necessarily confined to the specific use or uses thereof described above, since it may be utilized for any purpose to which it may be suited. Nor is the invention to be necessarily limited to the specific construction illustrated and described, since such construction is only intended to be illustrative of the principles of operation and the means presently devised to carry out said principles, it being considered that the invention comprehends any changes in construction that may be permitted within the scope of the appended claims.

I claim:

1. In equipment of the type including a tank in which objects are immersed in a cleaning liquid and cleaned therein by ultrasonic wave energy transmitted through the liquid by one or more transducers:

(a) at least one transducer extending along a wall of said tank and resonating in a multiplicity of differing fundamental modes and their harmonics, governed by correspondingly differing length, width, thickness, and diagonal dimensions of the transducer, said transducer including means having the property of vibrating in at least two different fundamental thickness modes plus the harmonics of each;

(b) an impulse-generating circuit for shock-exciting said transducer to produce simultaneous vibrations of the transducer in the several fundamental modes thereof, including

(1) a power supply means,

(2) a pulsing circuit that includes at least one triode the cathode of which receives energy from said power supply means, said pulsing circuit further including an impedance connected between the power supply means and the grid of the triode to produce a multiplicity of frequency components in the output wave form emitted by the anode of the triode, and

(3) an impedance matching coil connected between the power tube and transducer.

2. In equipment of the type including a tank in which objects are immersed in a cleaning liquid and are cleaned therein by ultrasonic wave energy transmitted through the liquid by one or more transducers:

(a) at least one transducer extending along a wall of said tank and resonating, in each of a plurality of differing physical dimensions thereof, in a multiplicity of differing fundamental modes and their harmonics; and

(b) a generator circuit that includes

(1) a power supply means;

(2) a pulsing circuit that includes at least one power tube receiving energy from said power supply means, said pulsing circuit also including an impedance that is connected between the power supply means and said tube to produce a multiplicity of frequency component in the output wave form of the power tube; and

(c) an impedance matching coil connected between the power tube and transducer.

3. In equipment of the type recited in claim 2 wherein said circuit effects shock plus steady state excitation of the transducer.

References Cited

UNITED STATES PATENTS

2,891,176	6/1959	Branson	68—3 X
3,075,097	1/1963	Scarpa	259—1 X
3,191,913	6/1965	Mettler	134—184 X
2,398,701	4/1946	Firestone	310—8.2
2,639,324	5/1953	Harvey	310—8.2
2,852,676	9/1958	Joy	310—8.1
3,152,295	10/1964	Schebler	310—8.2
3,117,768	1/1964	Carlin	310—8.1
3,180,626	4/1965	Mettler	310—8.2
3,223,907	12/1965	Blok	310—26
3,293,456	12/1966	Shoh	310—8.1
3,311,842	3/1967	Beck	310—8.7

MILTON O. HIRSHFIELD, *Primary Examiner.*

J. D. MILLER, *Assistant Examiner.*