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ULTRASONIC UNIT

Filed May 22, 1961

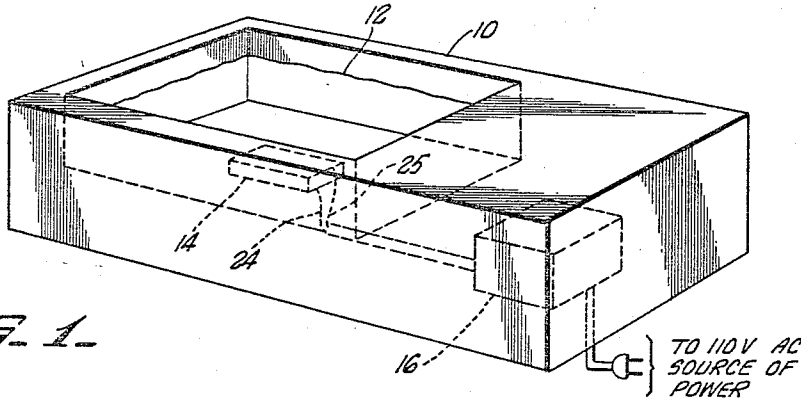


FIG. 1.

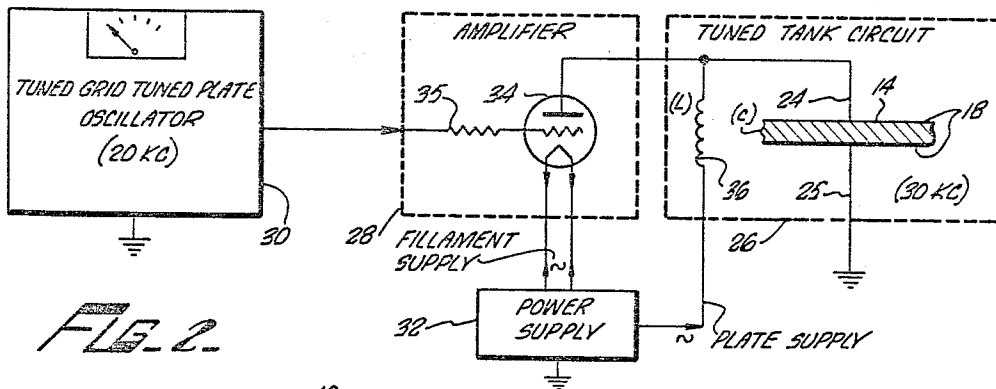


FIG. 2.

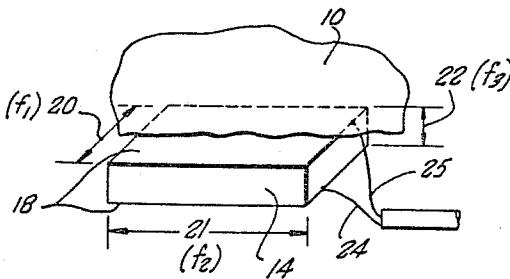


FIG. 3A.

$f_1 = 40 \text{ KC}$ DIMENSION 20 = $2\frac{1}{4}$ INCHES
 $f_2 = 20 \text{ KC}$ DIMENSION 21 = $4\frac{3}{8}$ INCHES
 $f_3 = 90 \text{ KC}$ DIMENSION 22 = $1\frac{1}{16}$ INCHES

FIG. 3B.

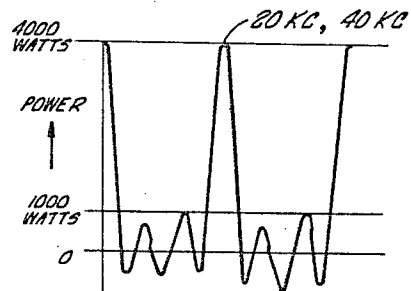


FIG. 4.

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This invention relates to piezoelectricity and more particularly to an improved apparatus for developing mechanical vibrations using a piezoelectric crystal element.

The use of vibratory energy for drilling, routing, cleaning, etc. is generally known. For example, ultrasonic cleaning apparatuses are generally known which use a single frequency mechanical vibration for cleaning action. Usually ultrasonic cleaning apparatuses have a cleaning tank for holding a cleaning media or wetting agent. Objects to be cleaned such as medical utensils, watch parts, clothing, etc. are placed in the cleaning media. Mechanical vibratory energy is applied to the cleaning tank, which in turn sets up mechanical vibrations in the cleaning media causing foreign particles to be removed from the objects being cleaned.

The mechanical vibratory energy is generally developed by a piezoelectric crystal element. A piezoelectric crystal element is used herein to refer to those crystals, such as Rochelle salt crystals and polarized barium titanate crystals, which mechanically vibrate when subjected to an electrical alternating current signal.

Piezoelectric crystals have resonant frequencies. Generally, useful vibratory energy may only be obtained from piezoelectric crystals at these resonant frequencies. In a parallelepiped piezoelectric crystal element, for example, three resonant frequencies are found. These resonant frequencies are approximately proportional to the dimensions between parallel surfaces of the crystal element.

Piezoelectric crystal elements have generally been energized with a single frequency electrical signal. The single frequency signal is applied between parallel surfaces of the crystal element. The frequency of the signal is equal to the resonant frequency of the crystal which is proportional to the dimension between the surfaces receiving the electric signals. Problems which this method of energization create are explained and eliminated in a co-pending application entitled Ultrasonic Cleaner bearing the Serial No. 56,170 and filed on September 15, 1960, now abandoned.

Generally, the vibratory energy available for cleaning action is low in ultrasonic cleaners. The amount of vibratory energy developed may be increased by increasing the amount of power applied to the crystal element. However, crystals dissipate power and an increase in the power applied to the crystal element causes power dissipation in the crystal to increase. A laboratory test was performed on a prior art cleaning apparatus using a parallelepiped crystal element having resonant frequencies at 20 kilocycles, 40 kilocycles and 90 kilocycles. In the test, 150 watts of power was first applied across the crystal element at 20 kilocycles and then at 40 kilocycles. At these frequencies, the vibratory energy applied to a five gallon cleaning tank by the crystal element was far below that required for useful cleaning action. Subsequently, 150 watts of power was applied across the same crystal element at 90 kilocycles. At 90 kilocycles, the crystal element overheated, cracked and became useless.

To reduce the amount of power loss in each crystal, a group of crystals have been connected in parallel. This again increases the expense of the ultrasonic cleaning unit due to the expense of the crystal elements.

Another method used to reduce the amount of power loss in each crystal is to add a large metallic heat sink to the crystal. However, this again increases the cost of the ultrasonic cleaner.

2

Previously, ultrasonic cleaners have been extremely sensitive to differences in loading. Therefore, whenever the liquid level in the cleaning tank or weight of objects being cleaned were changed, the frequency of energization had to be readjusted. This has been corrected in some instances by feedback circuits. However, this reduces the available power for cleaning action and is expensive.

Dead spots are found in the cleaning media of prior ultrasonic cleaning units. At these dead spots, very little useful vibratory energy is available for cleaning action. It has also been found that the cleaning action in prior known cleaners is the greatest at the center of the cleaning media in the cleaning tank and that around the outer edges of the cleaning media, the cleaning action is quite low.

Soft objects are cleaned most efficiently at lower frequencies, whereas harder objects are cleaned most efficiently at higher frequencies. Thus, prior known ultrasonic cleaning apparatus must provide means for energizing crystal elements separately at low frequencies for cleaning soft objects and at high frequencies for cleaning hard objects. The apparatus for this method of energization is expensive and separate steps are required for cleaning hard and soft objects. Also, these ultrasonic cleaners must be tuned and switched to two different frequencies.

Briefly, one embodiment of the present invention provides an ultrasonic cleaning unit with a piezoelectric crystal element having two harmonically related resonant frequencies. The piezoelectric crystal is in the shape of a parallelepiped.

An inductive impedance element is connected in parallel with the crystal element across two of its parallel surfaces. There is a de-energized value of capacitance across the two parallel surfaces of the crystal element. The inductance of the inductive element is adjusted relative to this capacitance such that the combination provides a tuned tank circuit with a resonant frequency equal to the mean value of the two resonant frequencies of the crystal element. An oscillator circuit is provided for developing a high frequency signal the frequency of which is substantially equal to that of one of the harmonically related resonant frequencies of the crystal element. An amplifier is used to couple the high frequency signals from the oscillator to the crystal element. This causes the crystal element to simultaneously mechanically vibrate at both the harmonically related resonant frequencies of the crystal element.

In the above-mentioned laboratory tests on the prior art cleaning apparatus, a piezoelectric crystal element having resonant frequencies of 20 kilocycles, 40 kilocycles and 90 kilocycles was tested in an embodiment of the present invention. The oscillator circuit was set to provide signals at a frequency of 20 kilocycles and the inductive element was adjusted to provide a resonant circuit at 30 kilocycles. The crystal element was energized with 150 watts of power. The crystal element was found to be so efficient that at 70° F. ambient temperature, the temperature of the crystal only rose to about 110° to 113° F. indicating an extremely low power loss. In addition, a uniform cleaning action was noted throughout the entire cleaning media in the tank.

During the tests on the embodiment of the present invention, it was also found that the ratio of the peak instantaneous power to average power delivered to the crystal element was about 27 to 1. This is in contrast to prior art cleaning apparatuses where this same ratio was about 4 to 1. It is extremely important to keep the ratio of peak instantaneous power to average power as high as possible because the peak power provides the actual cleaning action whereas the average power just heats up the crystal and attached structure. It was also found that the ultrasonic cleaning unit is virtually independent of

loading and returning is not required as the load changes. Additionally hard and soft objects may be cleaned at the same due to the simultaneous high and low frequencies of vibration. The invention disclosed in this patent application is an improvement over the invention described and claimed in a co-pending patent application, Serial No. 56,170 filed September 15, 1960, now abandoned, which was re-filed as a continuing patent application on July 5, 1963, bearing the Serial No. 294,223.

A better understanding of the present invention may be had with reference to the following detailed description and figures, in which:

FIGURE 1 is a perspective view partially broken away of an ultrasonic cleaning unit and embodying the present invention;

FIGURE 2 is a schematic-block diagram of the electrical circuits of FIG. 1;

FIGURE 3A is a perspective view of a parallelepiped piezoelectric crystal element for use in the ultrasonic cleaning unit of FIG. 1;

FIGURE 3B is a table showing the resonant frequencies and the dimensions of the piezoelectric crystal element of FIG. 3A; and

FIGURE 4 is a wave shape diagram showing the power wave form applied to the crystal element of FIG. 3A during operation.

Refer now to FIG. 1. FIGURE 1 shows an ultrasonic cleaning unit. The cleaning unit comprises a metallic container unit or cleaning tank 10 having a cavity in which a cleaning solution or other cleaning media 12, such as water, is placed. Objects to be cleaned are placed in the solution 12 within the cavity. A piezoelectric crystal element 14 is attached to the bottom of the cavity. A source of electric signals 16 for energizing the piezoelectric crystal element 14 is located at one end of the cleaning tank 10. The source 16 provides high frequency electrical signals to the crystal element 14 causing the crystal element 14 to vibrate the cleaning tank 10. The vibration energy set up in the cleaning tank 10 in turn causes vibration energy throughout the cleaning media 12 causing foreign particles to be removed from objects placed in the cleaning media 12.

Refer now to FIG. 3A. FIGURE 3A shows the crystal element 14 and a portion of the bottom of the cavity of the cleaning tank 10. The crystal element 14 is in the shape of a parallelepiped. The parallel surfaces are separated by the dimensions represented by the symbols 20, 21 and 22. Corresponding to the dimensions 20, 21 and 22, the crystal element 14 has three resonant frequencies represented by the symbols f_1 , f_2 and f_3 , respectively. The parallel surfaces separated by the dimension 22 have metallic surfaces or electrodes 18. The metallic surfaces 18 may be conductors such as silver which is plated or sprayed on the surfaces by means of a number of well-known processes. One of the metallic surfaces 18 is connected to the bottom of the cavity by means of a non-hardening cement, or other means which will not deteriorate or break loose due to mechanical vibrations in the crystal element 14.

FIGURE 3B shows the values of the resonant frequencies f_1 , f_2 and f_3 and the corresponding dimensions of the crystal element of FIG. 4. As indicated, the three frequencies, f_1 , f_2 and f_3 , are equal to 40 kilocycles, 20 kilocycles and 90 kilocycles, respectively. It should be noted at this point that the frequencies f_1 and f_2 are harmonically related to each other. Also, the frequency f_2 is the fundamental frequency and the frequency indicated by the symbol f_1 is the second harmonic frequency of the primary frequency f_2 . A typical barium titanate crystal element having these resonant frequencies has the dimensions 20, 21 and 22 equal to two and one-quarter inches, four and three-eighths inches and one and one-sixteenth inches, respectively, indicated in FIG. 3B.

With the general arrangement of the ultrasonic cleaner of FIG. 1 in mind and the details of the dimensions and

resonant frequencies of the crystal element 14 of FIG. 3A in mind, refer generally to the schematic-block diagram of FIG. 2. A source of signals or an oscillator circuit 30 is provided for developing high frequency signals. An amplifier circuit 28 couples the signals from the oscillator circuit 30 to a tuned tank circuit 26. A power supply 32 provides power to the tuned tank circuit 26 and the amplifier 28.

The oscillator 30 is a conventional type tuned grid tuned plate oscillator generally known in the electronics art. The tuned grid tuned plate oscillator 30 provides output signals having a frequency equal to one of the resonant frequencies of the crystal element 14. In FIG. 2, the frequency of the output signal from the oscillator 30 is equal to 20 kilocycles which is the frequency of the lower of the two harmonically related resonant frequencies of the crystal 14.

The amplifier circuit 28 comprises a conventional heated cathode type of triode vacuum tube 34 having its grid electrode connected through a parasitic suppressor resistor 35 to the output circuit of the oscillator circuit 30. The cathode electrode of the vacuum tube 34 is connected to a filament power supply in the power supply 32. The signals to the amplifier circuit 28 are such that the vacuum tube 34 is operated in class C.

The tuned tank circuit 26 comprises the piezoelectric crystal element 14 connected in parallel with an inductive impedance element 36. The surfaces 18 of the piezoelectric crystal element 14 are connected to two lead wires 24 and 25. The lead wire 25 is connected to ground (zero volts potential). The lead wire 24 is connected to one end of the inductive impedance element 36 and a plate of the vacuum tube 34. The other end of the inductive impedance element 36 is connected to the plate power supply in the power supply 32. The piezoelectric crystal element 14 has a predetermined value of capacitance between the surfaces coated with the metallic electrodes 18. Also, the inductive impedance element 36 has a certain value of inductance. The ratio of the inductance of the impedance element 36 to the capacitance of the piezoelectric crystal element 14 is such that the tuned tank circuit 26 has a resonant frequency equal to 30 kilocycles, exactly equal to the mean of the harmonically related resonant frequencies 40 kilocycles and 20 kilocycles.

Tests were performed on an ultrasonic cleaning unit having the electrical components shown in FIG. 2. In the tests, the dual frequencies of 20 kilocycles and 40 kilocycles were observed and the peak power applied to the crystal element was measured. This test was performed using a dual trace oscilloscope and observing both the current and voltage wave form through the crystal element 14. The oscilloscope was calibrated so that both voltage and current had the same peak amplitude. Voltage and current were found to be essentially in phase. FIGURE 4 shows the wave shape of the power applied across the crystal element 14 during this test. As indicated, the peak value of the power delivered to the crystal element is about 4,000 watts and the average power very much lower.

It should be understood that the present invention is not restricted to that shown in the drawings but other circuit arrangements may be devised and yet come within the present invention as defined by the claims. For example, the harmonically resonant frequencies of the crystal element are not restricted to first and second harmonics but other harmonically related frequencies may be used. Also, the frequency developed by the oscillator 30 may be equal to the upper harmonically related frequency rather than the lower. The resonant frequency is not restricted to the mean frequency but may be other values in between the upper and lower harmonically related frequencies.

It should also be understood that the crystal element 14 may be simultaneously energized at all three resonant frequencies at once by using a crystal element having a third frequency f_3 that is in harmonic relation to the other

resonant frequencies f_1 and f_2 . Also a plurality of crystal elements may be used rather than just one.

The present invention is not limited to an ultrasonic cleaning unit but may be incorporated in ultrasonic or vibrating drilling or routing apparatus or other apparatus using mechanical vibratory energy.

What is claimed is:

1. A vibratory cleaning unit the combination comprising a cleaning tank, a piezoelectric crystal element mounted for providing mechanical vibratory energy to said cleaning tank, said piezoelectric crystal element having dimensions determinative of at least two harmonically related resonant vibrating frequencies and a pair of surfaces for receiving electrical energy having a predetermined value of capacitance therebetween, means for forming an energizing signal for said crystal element having a substantially constant frequency substantially equal to one of said harmonically related frequencies and an inductive impedance element arranged having a value of inductance relative to said value of capacitance and coupled across said pair of surfaces for causing said crystal element to simultaneously vibrate at both said harmonically related frequencies for providing substantially uniform cleaning action to the cleaning tank with changes in loading in the cleaning tank.

2. In a mechanical vibratory energy generating apparatus the combination, comprising:

a piezoelectric crystal element having dimensions determinative of at least two harmonically related resonant mechanical vibratory frequencies of the crystal, and means for applying an energizing signal to the crystal element having at least two frequency components substantially equal to said two harmonically related resonant vibratory frequencies, said energizing means being adapted for applying an energizing signal of sufficient power at both of said frequencies for causing the crystal element to form mechanical vibratory power at both said harmonically related resonant vibratory frequencies.

3. In a mechanical vibratory energy generating apparatus the combination, comprising:

a piezoelectric crystal element arranged for forming mechanical vibratory energy and having dimensions determinative of at least two harmonically related resonant vibratory frequencies, means for applying an energizing signal to the crystal element having a frequency substantially equal to one of said harmonically related resonant vibratory frequencies, and means comprising an inductive impedance coupled to the crystal element and adapted for causing the crystal element to form mechanical vibratory power, in response to said energizing signal, having frequency components substantially equal to both of said harmonically related vibratory frequencies.

4. A mechanical vibratory energy generating apparatus the combination, comprising:

a piezoelectric crystal element having dimensions determinative of at least two harmonically related resonant mechanical vibratory frequencies, a source of alternating current signals having a frequency substantially equal to one of said harmonically related resonant mechanical vibratory frequencies, first means responsive to the alternating current signal for applying an energizing signal across the crystal element, and second means comprising an inductive impedance coupled to the crystal element and adapted for causing the crystal element to form vibratory power, in response to said energizing signal, having frequency components substantially equal to both said harmonically related resonant vibratory frequencies, said first means additionally comprising isolation means adapted for substantially isolating electrical signals formed by the crystal and said means

comprising said inductive impedance means from the signal source.

5. A mechanical vibratory energy generating apparatus the combination, comprising:

a piezoelectric crystal element having dimensions determinative of at least two harmonically related resonant mechanical vibratory frequencies, a source of alternating current signals having a frequency substantially equal to the lower one of said harmonically related resonant mechanical vibratory frequencies, first means responsive to the alternating current signal for applying an energizing signal across the crystal element, and second means comprising an inductive impedance coupled to the crystal element and adapted for causing the crystal element to form vibratory power, in response to said energizing signal, having frequency components substantially equal to both said harmonically related resonant vibratory frequencies, said first means comprising isolation means for substantially isolating electrical signals formed by the crystal and said inductive impedance means from the signal source.

6. A mechanical vibratory energy generating apparatus the combination, comprising:

a piezoelectric crystal element having dimensions determinative of at least two harmonically related resonant mechanical vibratory frequencies, one of said resonant mechanical vibratory frequencies being substantially twice the other, a source of alternating current signals having a frequency substantially equal to the lower one of said harmonically related resonant mechanical vibratory frequencies, first means responsive to the alternating current signal for applying an energizing signal across the crystal element, and second means comprising an inductive impedance coupled to the crystal element and adapted for causing the crystal element to form vibratory power, in response to said energizing signal, having components substantially equal to both said resonant frequencies, said first means comprising isolation means for substantially isolating electrical signals formed by the crystal and said means comprising said inductive impedance means from the signal source.

7. A mechanical vibratory energy generating apparatus the combination, comprising:

a piezoelectric crystal element arranged for forming mechanical vibratory energy and having at least two substantially flat parallel surfaces having metallic surfaces thereon with a predetermined value of capacitance therebetween and including dimensions determinative of at least two harmonically related resonant mechanical vibratory frequencies, a source of alternating current signals having a frequency substantially equal to the lower one of said harmonically related mechanical vibratory frequencies, means responsive to the alternating current signals for applying an electrical energizing signal of substantially the same frequency across the metallic surfaces on said crystal element, and an inductive impedance element electrically coupled in parallel with the energizing signal across the metallic surfaces and having a value of inductance such that together with said capacitance a tuned circuit is formed having a resonant frequency substantially equal to the mean frequency of said harmonically related vibratory frequencies and thereby cause the crystal element to form vibratory power, in response to said electrical energizing signal, having frequency components substantially equal to both of said harmonically related mechanical vibratory frequencies, said energizing signal means comprising isolation circuit means for substantially isolating electrical signals formed in the tuned circuit from the signal source.

8. A mechanical vibratory energy generating apparatus as defined in claim 7 wherein one of the resonant

mechanical vibratory frequencies of the crystal element is substantially double the other resonant mechanical vibratory frequency, and wherein said isolation circuit means comprises a vacuum tube coupled between the crystal element and energizing signal means including a plate circuit coupled to the crystal element and a grid circuit coupled to the energizing signal means. 5

9. In a mechanical vibratory cleaning apparatus the combination, comprising:

a cleaning tank, a piezoelectric crystal element mounted for providing vibrating energy to the cleaning tank and having dimensions determinative of at least two harmonically related resonant mechanical vibratory frequencies, a source of alternating current signals having a frequency substantially equal to the lower one of said harmonically related resonant mechanical vibratory frequencies, first means responsive to said alternating current signals for applying an energizing signal across the crystal element of substantially the same frequency, and second means comprising an inductive impedance coupled to the crystal element and adapted for causing the crystal element to mechanically vibrate and apply mechanical vibratory power to the cleaning tank having frequency components substantially equal to both of said harmonically related resonant mechanical vibratory frequencies, said first means comprising isolation circuit means for substantially isolating electrical signals formed by the crystal and said inductive impedance means from the signal source. 30

10. In a mechanical vibratory cleaning apparatus the combination, comprising:

a cleaning tank, having a bottom and sides, a piezoelectric crystal element for providing mechanical vibratory energy to the cleaning tank and having at least two substantially flat parallel surfaces having metallic surfaces thereon with a predetermined value of capacitance therebetween, the crystal element having dimensions determinative of at least two harmonically related resonant mechanical vibratory frequencies one of which is substantially twice the other, the crystal being mounted on said tank with said 35

parallel surfaces and said dimensions positioned substantially parallel with the bottom of said tank, a constant frequency oscillator circuit for forming a signal having a frequency substantially equal to the lower one of said harmonically related resonant vibratory frequencies, an electrical circuit arranged to be responsive to the oscillator signal for applying an energizing signal across the metallic surfaces of said crystal element of substantially the same frequency, and an inductive impedance element coupled in parallel with the energizing signal across the metallic surfaces and having a value of inductance such that together with the capacitance a tuned circuit is formed having a resonant frequency approximately equal to the mean frequency of said vibratory frequencies for causing the crystal element to provide sharp peaks of substantially uniform mechanical vibratory power throughout any cleaning liquid placed in the cleaning tank having frequency components substantially equal to both of said harmonically related mechanical vibratory frequencies, said electrical circuit comprising a vacuum tube having a plate circuit coupled to one of the surfaces of the crystal element and a grid circuit coupled to the oscillator circuit for substantially isolating electrical signals formed in the tuned circuit from the oscillator circuit.

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