

**June 16, 1959**

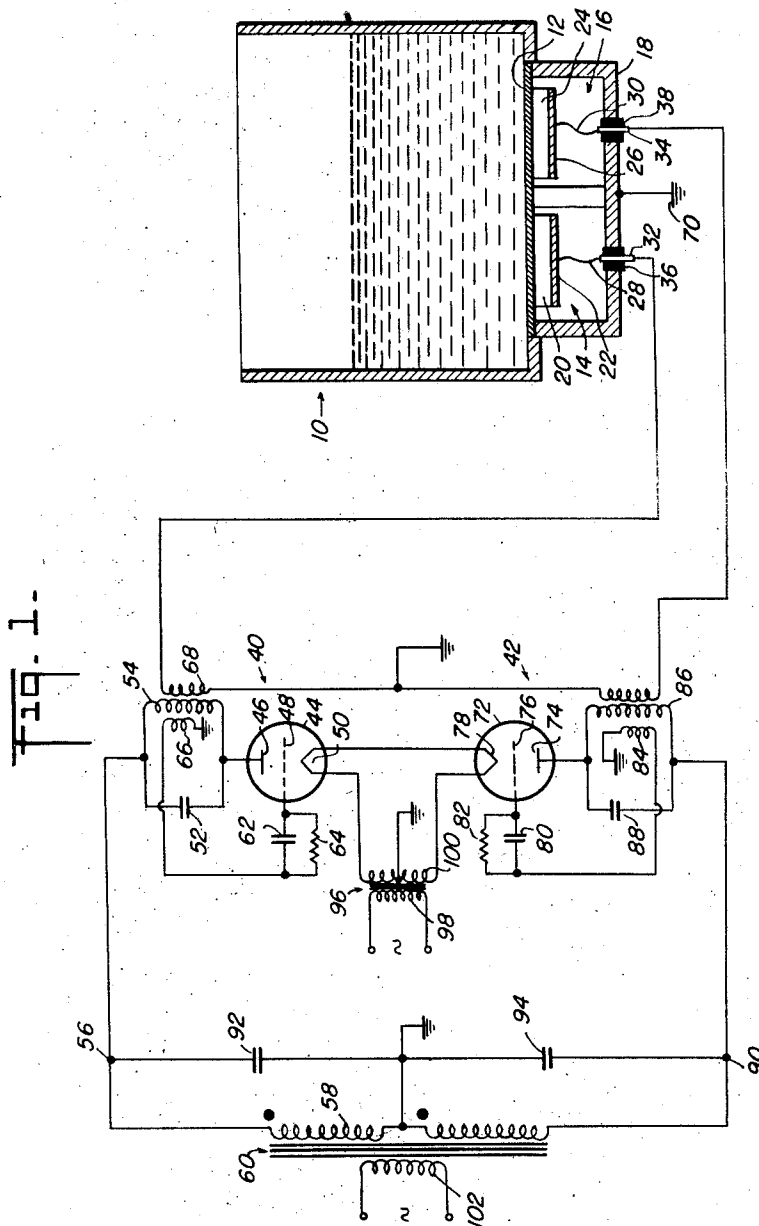
N. G. BRANSON

**2,891,176**

# COMPRESSIONAL WAVE GENERATING APPARATUS

Filed July 13, 1955

2 Sheets-Sheet 1



INVENTOR.

*Norman G. Branson*

**BY**

Churchill, Fish, Allynworth & Engel  
Attorneys

*Attorneys*

June 16, 1959

N. G. BRANSON

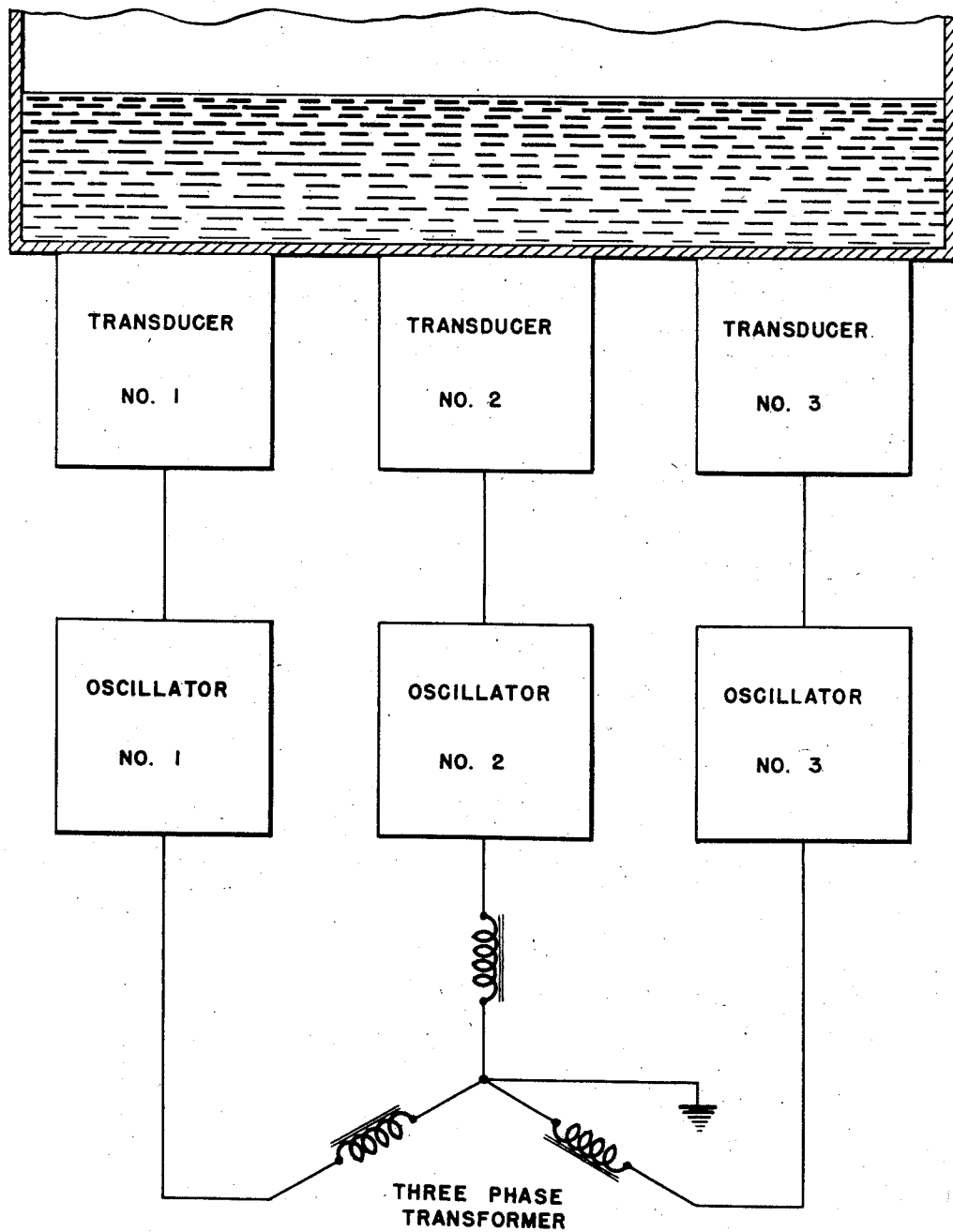
2,891,176

COMPRESSIONAL WAVE GENERATING APPARATUS

Filed July 13, 1955

2 Sheets-Sheet 2

Fig. 2



1

2,891,176

## COMPRESSONAL WAVE GENERATING APPARATUS

Norman G. Branson, Stamford, Conn., assignor to Branson Instruments, Inc., Stamford, Conn., a corporation of Connecticut

Application July 13, 1955, Serial No. 521,764

13 Claims. (Cl. 310—8.1)

The present invention relates to apparatus for generating sonic or ultrasonic vibrations and finds particular utility in ultrasonic compressional wave apparatus having compressional wave transducing means for working into a compressional wave propagating medium.

An important known industrial application of ultrasonic compressional wave energy is in the cleaning of a variety of objects by immersion in a cleaning solution through which the ultrasonic wave energy is propagated. In the simplest case an electronic oscillator is arranged to generate a continuous high-frequency wave which is employed to excite an electromechanical transducer consisting of a piezoelectric or magnetostrictive element. The transducer is placed in suitable communication with the interior of a tank or other container in which is placed the cleaning fluid. Now, if the transducer is supplied with continuous-wave exciting power in excess of a predetermined minimum, objects can be cleaned upon being immersed in the path of the compressional wave beam. The time required is only a few seconds.

It has been found, however, that improved results can be obtained by exciting the transducer with bursts of energy by keying or otherwise pulsing the source of high-frequency energy instead of supplying the transducer with continuous excitation. In this manner the average power can be reduced while maintaining the peak power in excess of said predetermined minimum value. Because commercial electrical power is normally supplied having a frequency of 60 cycles per second, keying rates of both 60 and 120 bursts per second have been investigated. Employing 120 bursts per second resulted in a noticeable improvement in cleaning efficiency over that obtained with continuous excitation. It has been discovered, however, that 60 bursts of high-frequency energy per second, at the same average power as 120 bursts per second, produces a still further improvement, estimated as a 50 percent improvement in cleaning efficiency over that obtained with 120 bursts. The theoretical explanation for this unexpected increase in cleaning efficiency is not known at this time, although it is thought that it may have something to do with surface cavitation effects on the face of the transducer and on the effect of gas bubbles which are always present in ultrasonically irradiated liquids.

A very simple circuit arrangement for obtaining exciting current having a burst repetition rate of 60 cycles per second consists of a self-excited vacuum tube oscillator whose plate circuit is connected directly across the terminals of the secondary winding of a power transformer and whose high-frequency output is coupled to the transducer. The oscillator tube is self-rectifying whereby the oscillator will oscillate at its tuned frequency on alternate half cycles of the supply frequency. This arrangement, however, has one major drawback. The rectifying effect of the oscillator causes a relatively high direct current component to flow through the secondary winding of the transformer and this is reflected into the primary winding. In order to handle this current, the

2

transformer must be provided with iron and copper in excess of that required to handle the useful power supplied to the oscillator. Such factors as core saturation and heat dissipation must be considered. The presence of the direct current can account for as much as a 50% increase in the size of the transformer.

It is an object of the present invention to provide means whereby the compressional wave transducer or transducers can be operated at a burst rate of 60 cycles per second to take advantage of the increased cleaning efficiency which results therefrom without drawing a net direct current from the power transformer. As a corollary it is an object of the invention to provide a more efficient and less costly ultrasonic wave generator than those presently available.

Further objects and advantages will become apparent from the following detailed description taken in conjunction with the accompanying drawings which are a schematic representation of the present preferred embodiment of the invention.

Fig. 1 represents schematically one embodiment of the invention; and Fig. 2 represents an alternative embodiment.

Referring to the drawing of Fig. 1, the cleaning tank is shown generally at 10, partially filled with cleaning fluid. In this particular embodiment, the bottom of the tank is fitted with a flexible diaphragm 12 which might be formed from stainless steel. A plurality of compressional wave transducers 14 and 16 are located within compartments of a housing 18 below the diaphragm 12. Transducer 14 comprises a piezoelectric element 20 having one surface in both electrical and mechanical contact with the diaphragm 12 and the opposite surface in contact with an electrode 22. In similar manner the transducer 16 has a piezoelectric element 24 and an electrode 26. Electrical conductors 28 and 30 join the electrodes 22 and 26 with input terminals 32 and 34, respectively, which are electrically isolated from the housing 18 by the insulating material 36 and 38.

It is to be understood that the compressional wave transducer described above with reference to the drawing has been shown and described in simplified schematic form with no attempt being made to show the actual construction. Such transducers are well known in the art and in themselves form no part of the present invention. As will hereinafter appear, it is necessary to have at least two separately excited, mutually independent transducer sections or banks. However, it is immaterial whether the two sections be considered as part of a single transducer or as separate and complete transducers. Although only two elements have been shown in the drawing, it is contemplated that any number of elements may be employed if their load is properly distributed in the manner to be described. Furthermore, magnetostrictive elements may be employed in place of piezoelectric, as is well understood; and the different transducer sections need not be located in the same wall of the tank or coupled with the same propagating medium.

In order to supply the transducers 14 and 16 with exciting current there are provided two self-excited oscillators generally indicated at 40 and 42. Oscillator 40 is shown as a plate-tuned oscillator comprising a vacuum tube 44 having a plate electrode 46, a control grid 48 and a hot cathode 50. A tank circuit consisting of the capacitor 52 and inductance 54 is connected between the plate electrode 46 and the terminal 56 of the center-tapped secondary winding 58 of the power transformer 60. The control grid 48 is connected to ground through the biasing capacitor 62, resistor 64 and tickler feedback winding 66. The feedback winding 66 is coupled to the inductance 54 in order to couple the grid 48 to the plate circuit. The oscillator 40 is also provided with an out-

put winding 68 inductively coupled to the inductance 54 and connected between the terminal 32 of the transducer and ground. The conductive housing 18 of the transducer is also connected to ground at 70.

In a similar manner, oscillator 42 is provided with a vacuum tube 72 having a plate electrode 74, a control grid 76 and a hot cathode 78. The grid 76 is connected through capacitor 80, resistor 82 and tickler feedback winding 84 to ground. The winding 84 is inductively coupled to the inductance 86 which, with the capacitor 88, forms a tank circuit coupled between the plate electrode 74 and the terminal 90 at the opposite end of the transformer secondary winding 58.

A low impedance path for the high-frequency energy is provided by the by-pass capacitors 92 and 94 shunting corresponding halves of the secondary winding 58.

Current for heating the cathodes of the tubes 44 and 72 is supplied by the filament transformer 96 which has a primary 98 for connection to the commercial power mains or other power source and a center-tapped secondary 100, connected in series with the cathodes 50 and 78, as shown. The center-tap of secondary 100 is connected to ground to provide a balanced return path for the plate currents of the tubes 44 and 72 in a well known manner.

The generator circuit is completed by providing the transformer 60 with a primary winding 102 for connection to the same or similar source of power as that to which winding 98 is connected. Preferably the source connected to the primary winding 102 has a frequency of 60 cycles per second.

The operation of the circuit will now be described. Let it be assumed that at a given moment the potential of the terminal 56 of the transformer winding 58 is just commencing to go positive with respect to ground potential. The potential of the opposite terminal 90 will, thus, be commencing to go negative with respect to ground. During the ensuing half cycle of the current supplied to the primary winding 102, the plate electrode 46 of tube 44 will be positive with respect to the cathode 50 and the circuit 40 will oscillate. The circuit will oscillate at a frequency determined by the elements 52 and 54 and by other related factors, all in a known manner. By way of example, it can be assumed that oscillator 40 operates at 40 kilocycles per second. Therefore, during the first half cycle of the power source a 40 kilocycle burst of energy will be supplied via winding 68 to the transducer 14. As is well known, the piezoelectric element 20 will set up mechanical vibrations in the diaphragm 12 which will be communicated to the liquid in the container 10. Because of the ultrasonic frequency, the compressional waves produced are highly directive in nature and travel substantially in a straight line to the surface of the fluid. Due to the negative swing of the transformer terminal 90 during this interval, the oscillator 42 will be inoperative and the transducer 16 will be substantially quiescent.

During the following half cycle of the line current the potentials of the terminals 56 and 90 will reverse with respect to ground potential causing the oscillator 42 to operate while the oscillator 40 remains dormant. Preferably oscillator 42 also operates at 40 kilocycles, i.e., the same frequency as oscillator 40. During this half cycle interval the transducer 16 is energized so as to radiate a compressional wave upward through the liquid medium in the tank 10. It has been found that the improved cleaning efficiency associated with the lower burst repetition rate of 60 cycles per second is still obtained in spite of the side-by-side relationship of the two transducer sections. This can be explained by the fact that the compressional waves of ultrasonic frequency are highly directive and, therefore, the liquid in the immediate vicinity of one transducer is not affected by operation of an adjacent transducer.

If the two oscillators 40 and 42 along with their respec-

tive loads are balanced as to power consumption, any direct current component induced into one half of the transformer secondary winding 58 by one oscillator will be opposed by an equal and opposite direct current component induced into the other half of the secondary winding by the other oscillator. Thus, the primary winding 102 of the power transformer 60 will see a pure alternating current load and will not be required to carry a direct current component. Stated differently, the net direct current flowing in the secondary winding as a whole will be zero.

From the above description of the operation of the illustrated apparatus the underlying principles should be clear. The load applied to the output of each oscillator may consist of a bank of transducer elements operating either in series or parallel. If the two oscillators are identical and the secondary winding of the power transformer is center-tapped then each bank of transducer elements must have the same electrical power requirements. If the two banks of transducer elements are unequal, then the oscillators may be suitably modified to achieve power balance with respect to the secondary winding 58 of the power transformer, or in the alternative, the secondary winding 58 may have its intermediate tap displaced from the winding center so that the two portions of the winding have unequal turns. It is also possible to extend the principle, as shown in Fig. 2, to a polyphase system wherein the secondary of the power transformer is provided with a Y winding with each branch of the Y connected to a separate power oscillator. Although plate-tuned oscillators have been shown in the drawing, it should be understood that any oscillator circuit may be employed so long as the arrangement is such as to place a balanced load upon the power transformer 60.

Although the invention has been described as applied to a cleaning process or apparatus it should be apparent that it may be applied to other processes or apparatus where ultrasonic wave production in a compressional wave propagating medium is useful. It is also contemplated that frequencies outside of the ultrasonic range may be employed while still taking advantage of the teachings of the present invention.

Having described the invention by reference to a preferred embodiment thereof, it is to be understood that it is merely illustrative of the invention which is not limited to the details hereinabove described but is to be construed broadly within the purview of the claims.

What is claimed is:

1. Compressional wave generating apparatus comprising a compressional wave transducer having first and second separately excited mutually independent sections for working into a common compressional wave propagating medium, a first electrical wave generator, a second electrical wave generator, said first and second generators being operatively coupled, respectively, to said first and second transducer sections for supplying exciting power thereto, the same amount of electrical power being required to operate each generator and its associated load, an electrical power transformer having a primary winding for connection to a source of alternating current and a secondary winding, and means directly coupling said secondary winding to said first and second generators for energizing said generators in phase opposition, said generators being alternately operative to generate a burst of oscillatory energy during opposite alternate half cycles of said source of alternating current, whereby a balanced load is placed upon said transformer while each transducer section is excited at a burst repetition rate equal to the frequency of said alternating current source.

2. Compressional wave generating apparatus comprising a plurality of compressional wave transducers, a first electrical wave generator, a second electrical wave generator, said first generator being operatively coupled to substantially half of said plurality of transducers and said second generator being operatively coupled to the remain-

5

der of said transducers for supplying exciting power thereto, the same amount of electrical power being required to operate each generator and its associated load, an electrical power transformer having a primary winding for connection to a source of alternating current and a secondary winding, and means directly coupling said secondary winding to said first and second generators for energizing said generators in phase opposition, said generators being alternately operative to generate a burst of oscillatory energy during opposite alternate half cycles of said source of alternating current, whereby a substantially balanced load having a negligible net direct current component is placed upon said transformer while each transducer is excited at a burst repetition rate equal to the frequency of said alternating current source.

3. Compressional wave generating apparatus comprising a compressional wave transducer having first and second separately excited mutually independent sections for working into a common compressional wave propagating medium, a first electrical wave generator, a second electrical wave generator, said first and second generators being operatively coupled, respectively, to said first and second transducer sections for supplying exciting power thereto, the same amount of electrical power being required to operate each generator and its associated load, an electrical power transformer having a primary winding for connection to a source of alternating current and a center-tapped secondary winding, and means directly coupling the halves of said secondary winding to said first and second generators, respectively, for supplying operating power thereto in phase opposition, said generators being alternately operative to generate a burst of oscillatory energy during opposite alternate half cycles of said source of alternating current, whereby a balanced load is placed upon said transformer while each transducer section is excited at a burst repetition rate equal to the frequency of said alternating current source.

4. Compressional wave generating apparatus comprising a compressional wave transducer having first and second separately excited mutually independent sections for working into a common compressional wave propagating medium, first and second self-excited power oscillators for generating oscillatory current when supplied with operating current having a given polarity, said first and second oscillators being operatively coupled, respectively, to said first and second transducer sections for supplying said oscillatory current thereto, an electrical power transformer having a primary winding for connection to a source of alternating current and a secondary winding having an intermediate tap, and means directly coupling the two portions of said secondary winding to said first and second oscillators, respectively, for alternately supplying said oscillators with operating current having the given polarity, said transformer secondary winding portion being proportioned along with said generators and their loads such that a balanced load is placed upon said transformer while each transducer section is excited at a burst repetition rate equal to the frequency of said alternating current source, whereby said primary winding is not required to carry a direct current component.

5. Compressional wave generating apparatus comprising a plurality of separately excited mutually independent compressional wave transducer means, a plurality of electrical wave generators for supplying exciting current to said transducers, the transducers being distributed between the outputs of said generators, said generators being of the type which draw a direct current component from an alternating current supply and generate bursts of oscillatory energy during alternate half cycles thereof, an electrical power transformer having a primary winding for connection to a source of alternating current and a multiphase secondary winding, and means connecting each phase of said secondary winding to a different one of said plurality of generators in a balanced arrangement for supplying alternating current thereto, said balanced arrangement resulting in cancellation in said secondary winding

6

of the direct current components drawn by said generators, whereby said transducers are excited at a burst repetition rate equal to the frequency of said source of alternating current without causing direct current to flow in said primary winding.

6. For use in compressional wave generating apparatus having compressional wave transducer means, separate sources of exciting current for separate portions of said transducing means comprising two or more electrical wave generators having separate outputs for supplying said separate sources, said generators being of the type which draw a direct current component from an alternating current supply and generate bursts of oscillatory energy during alternate half cycles thereof, an electrical power transformer having a primary winding for connection to a source of alternating current and a secondary winding, and means connecting said secondary winding to said plurality of generators in a balanced arrangement for supplying alternating current thereto, said balanced arrangement resulting in cancellation in said secondary winding of the direct current components drawn by said generators, whereby said separate portions of the transducer means will be excited at a burst repetition rate equal to the frequency of said source of alternating current without causing direct current to flow in said primary winding.

7. Polyphase ultrasonic compressional wave generating apparatus comprising in combination a plurality of electro-mechanical compressional wave transducers, a plurality of individual oscillatory generators of electrical energy at ultrasonic frequencies, each of said generators having separate power outputs, means for connecting the separate outputs of said generators individually to said transducers, and means for operating said individual generators successively in a predetermined sequence and at a predetermined repetition rate from a common source of alternating current electrical power, said last named means including means for sequentially pulsing said generators individually at a repetition rate corresponding to the frequency of said alternating current power source and for operating each generator in a sequence and for a time determined by the phase relation between the outputs of said generators.

8. The combination of claim 7 comprising a pair of oscillatory generators separately connected to a pair of electro-mechanical transducers, and means for operating said generators alternately whereby energy from each of said generators is alternately applied to said transducers alternately at a pulse rate corresponding to the frequency of said power source and at a phase displacement of 180 degrees.

9. The combination of claim 7 comprising three separate oscillatory generators respectively connected to three separate electro-mechanical transducers, and means for connecting said generators to a three phase alternating current power supply line whereby said generators are individually energized in sequence corresponding to the time displacement between the phases of said power source, and the output energy from each of said generators is pulsed at a rate corresponding to the line frequency of said power source.

10. Polyphase ultrasonic compressional wave generating apparatus comprising in combination a plurality of electro-mechanical compressional wave transducers, means for successively energizing and de-energizing said transducers in a predetermined polyphase sequence, said successive energizing means including a plurality of separate oscillatory generators driven by connection to a common alternating current power source, and pulse modulation means for modulating the energy output from each of said generators at a pulse repetition rate equal to the fundamental frequency rate of said alternating current power source.

11. The combination of claim 10 comprising a pair of separate oscillatory generators driven by connection to a

single phase alternating current power source, and means for operating each of said generators and its corresponding transducer alternately at a rate of interruption equal to the frequency of alternation of said power source.

12. The combination of claim 10 comprising three separate oscillatory generators driven by connection to a three phase alternating current power source, means connecting each of said generators to a separate electro-mechanical compressional wave transducer, means for operating each of said generators and its corresponding transducer successively and sequentially on a time cycle determined by the time displacement between successive phases of electrical energy from said power source, and means for modulating the operation of each of said generators and its corresponding transducer at a repetition rate determined by the frequency of said alternating current power source.

13. Polyphase ultrasonic compressional wave generating apparatus comprising in combination an alternating current source, a plurality of separate oscillatory gener-

ators each of which is adapted to convert energy from said source into electrical ultrasonic energy during a part of one half cycle of each cycle of energy applied to it from said source, means coupling said source to said generators to cause such half cycles applied to each generator to be different from the half cycles applied to every other generator, a plurality of electro-mechanical compressional wave transducers and means coupling each of said transducers to one of said generators to be driven by it, whereby each transducer is driven during a half cycle period different from every other generator and at a repetition rate equal to the frequency of said source.

#### References Cited in the file of this patent

##### UNITED STATES PATENTS

|           |                     |               |
|-----------|---------------------|---------------|
| 1,734,975 | Loomos et al. ....  | Nov. 12, 1929 |
| 2,554,701 | Hackett et al. .... | May 29, 1951  |
| 2,578,505 | Carlin .....        | Dec. 11, 1951 |
| 2,650,872 | Goldwasser .....    | Sept. 1, 1953 |