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 [21] Appl. No. **730,398**
 [22] Filed **May 20, 1968**
 [45] Patented **June 1, 1971**
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[54] **ULTRASONIC DISHWASHER**
4 Claims, 4 Drawing Figs.

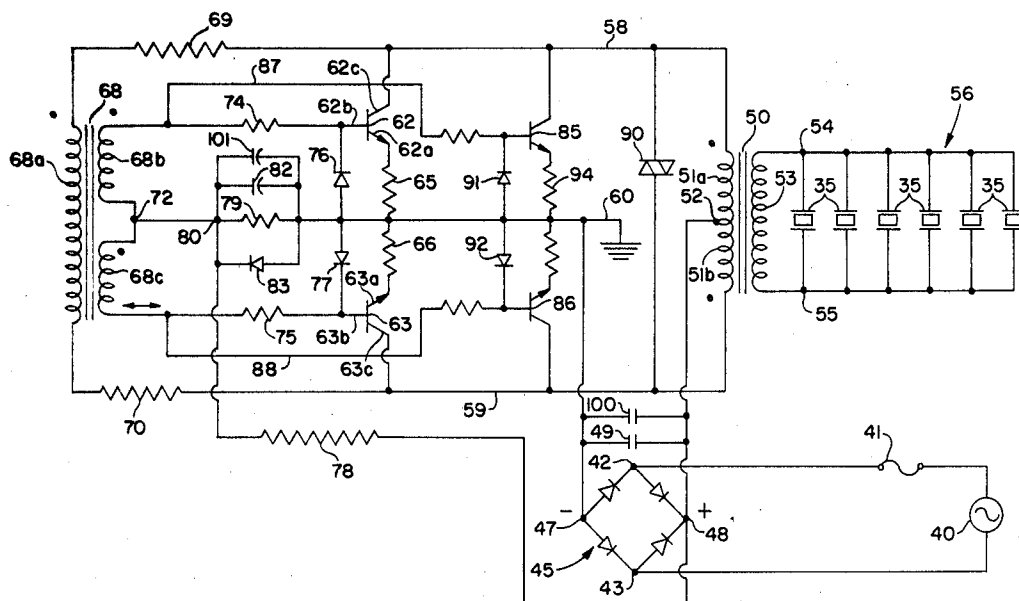
[52] U.S. Cl. **318/116,**
310/8.1, 321/45, 259/1

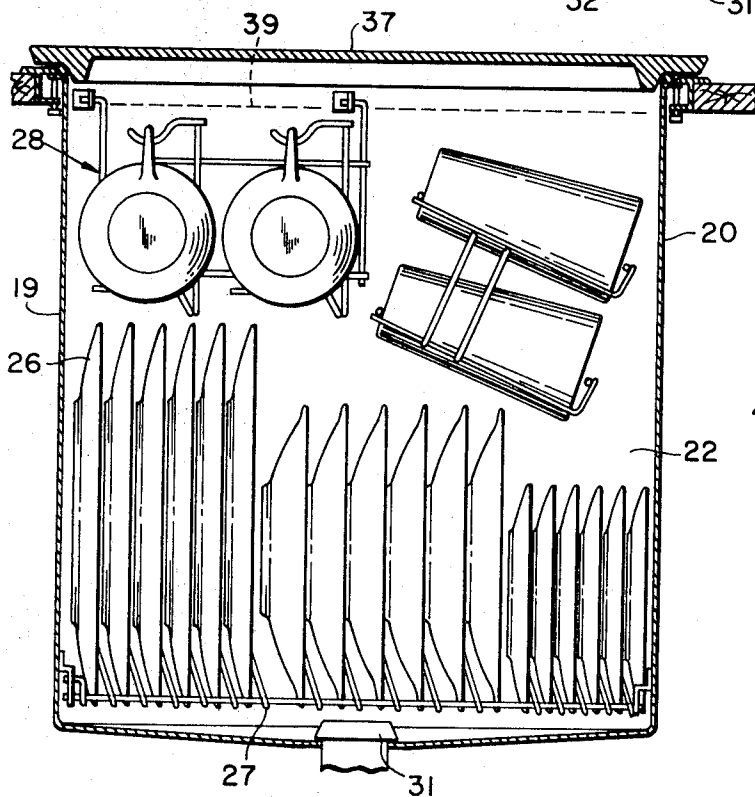
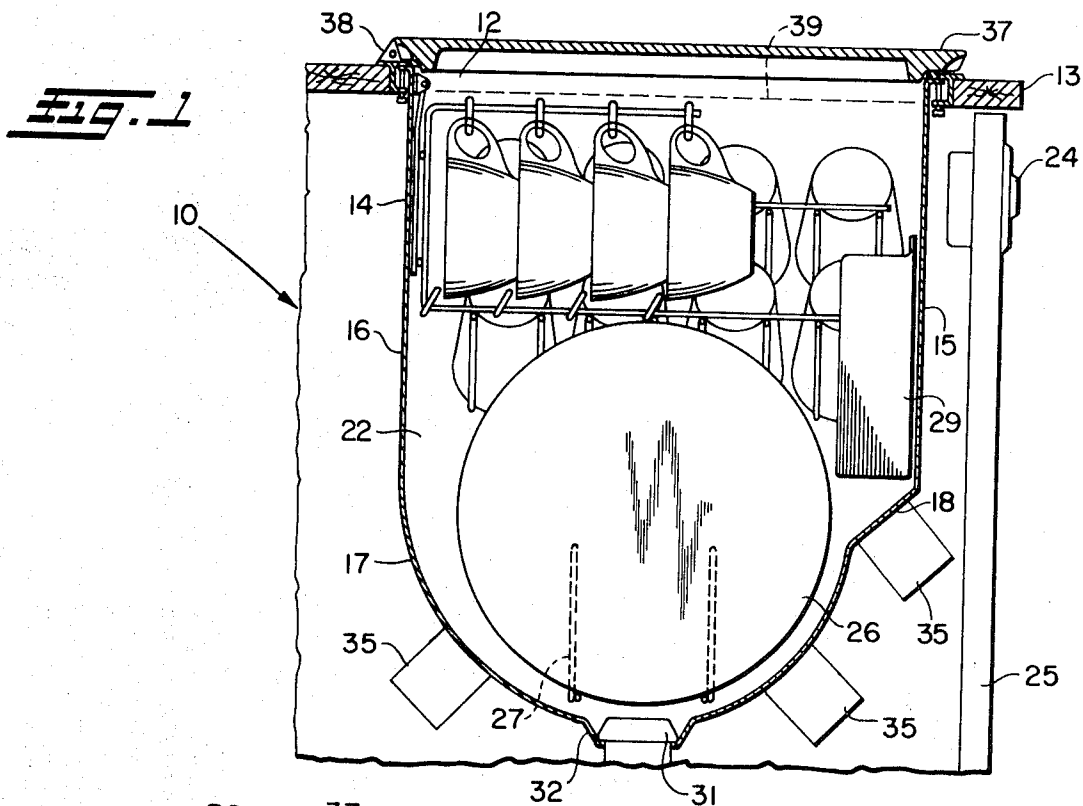
[51] Int. Cl. **H01v 7/00**

[50] Field of Search **310/8.1,**
8.2, 26; 318/116, 118; 321/2, 4, 45, 18; 359/1 SS

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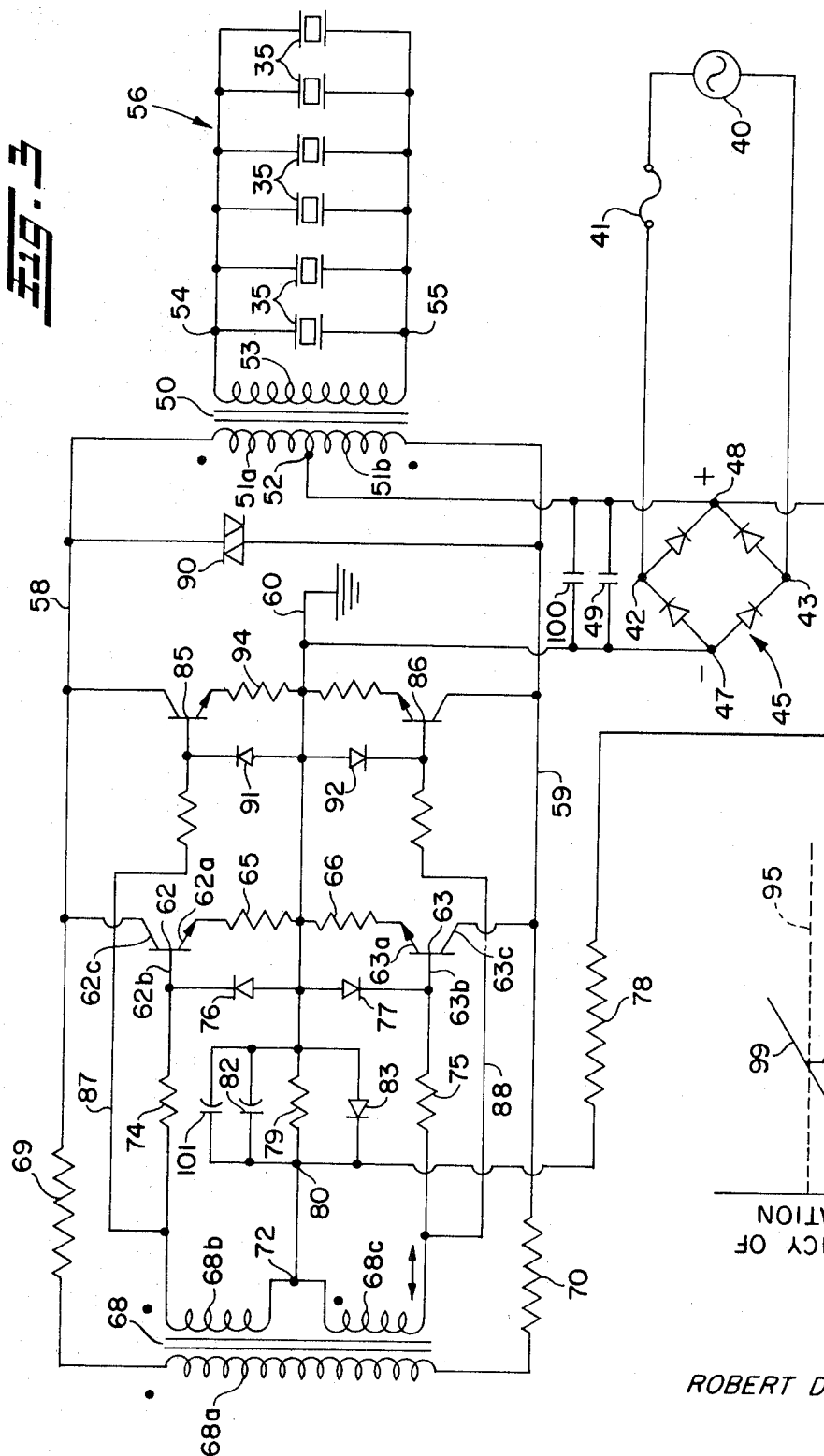
ABSTRACT: Apparatus for supplying ultrasonic energy to a dishwasher consisting of a piezoelectric transducer arrangement associated with the washer chamber and a saturable core transformer, inverter-type circuit for energizing the transducers at high frequencies. Line voltage is utilized as the power source and "ripple voltage" provides variation in the inverter output frequency to prevent standing waves of ultrasonic energy in the washer chamber.





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ULTRASONIC DISHWASHER

DISCLOSURE

This invention relates to ultrasonic dishwashers and more particularly to electronic circuits for energizing ultrasonic transducers in a varying frequency mode of operation.

The art of ultrasonic cleaning has received much consideration in the past and has become of importance in the domestic dishwasher field of interest. One of the significant considerations in this type of commercial embodiment is the attention which must be directed to an economical and simplified arrangement for producing the desired results commensurate with effectiveness of cleaning.

It is well known that ultrasonic cleaning operates on the principle of creating cavitation and vibration in a cleaning medium to effect a separation of soil particles from dishware and the like and to provide a measure of emulsification of oils and fats. The cavitation effect relates specifically to the action which occurs at the interface between the soil and the item of dishware and its effect is directly proportional to the impedance difference occurring thereat. Vibration effects set up by the cleaning medium occur as energy waves which travel through the soil particles primarily normal to a particular interface. Both of these effects are further aided by the emulsification of fatty materials which aids the separation of the soil particles and effects a dispersion of same throughout the cleaning medium.

It is also known that the efficiency of the cleaning operation is dependent upon the manner of application of such ultrasonic energy.

Thus, in cavities such as a dishwasher enclosure, a specific distribution of the energy will occur, dependent upon the frequency of operation and the physical characteristics of the cavity, such that nodes of energy or the appearance of standing waves will occur. Such condition will cause localized cleaning effects and the avoidance of such condition has received much attention in the prior art. For such a frequency dependent system, it would be desirable to modulate the frequency of energization of the transducers to, in effect, sweep the applied frequency about an optimum level of operation. Such approach will cause a condition of continuously changing wave patterns related to the sweep frequency of the system and if sufficient variance is provided, an effective cleaning operation can be obtained.

The prior art indicates that this effect has been accomplished, for example, by the utilization of two or more signal generating systems wherein generator outputs are combined to achieve some form of modulation or sequential switching of the generators may be performed to provide a variable frequency condition. Further, substantial efforts have been directed toward combining an electrical frequency generator for energizing an ultrasonic transducer with mechanical means for disturbing the system to provide a random and constantly varying distribution of the energy within the cavity. Most of these systems require a substantial amount of apparatus and are unduly expensive and complicated and it is a primary object of this invention to provide an improved ultrasonic frequency generator which has a sweep provision inherent therein and which is more economical and dependable than prior art systems.

It is another object of this invention to provide an improved ultrasonic frequency generator which utilizes semiconductor and passive components entirely within the circuit and which receives its source of supply from the readily available household power lines.

It is a further object of this invention to provide an improved ultrasonic frequency generator which is more efficient and reliable than previous known devices and which may be readily incorporated in a commercial appliance.

Other objects and advantages of the present invention will become apparent as the following description proceeds.

To the accomplishment of the foregoing and related ends, the invention, then, comprises the features hereinafter fully

described and particularly pointed out in the claims, the following description and the annexed drawings setting forth in detail certain illustrative embodiments of the invention, these being indicative, however, of but a few of the various ways in which the principle of the invention may be employed.

In said annexed drawings:

FIG. 1 is a cross-sectional side view of a dishwasher enclosure showing the relationship of the ultrasonic transducers to the cleaning cavity;

FIG. 2 is a cross-sectional front view of the dishwasher of FIG. 1;

FIG. 3 is an electrical circuit diagram of the preferred embodiment of this invention shown in relation to a typical load arrangement comprising six ultrasonic transducer crystals;

FIG. 4 is a graph showing the output frequency of the electrical circuit as related to impressed DC volts.

Referring now to FIGS. 1 and 2, there is shown a dishwasher 10 which is a typical application for the teachings of this invention. It should be understood, however, that this invention may be applicable as well to other types of cleaning devices or forms of apparatus which rely on the application of ultrasonic energy to perform some useful function. The dish washer 10 is shown mounted in an opening 12 within cabinet 13 and comprises a water tight sheet metal enclosure 14 having essentially vertical front and rear walls 15, 16 respectively, a cylindrical bottom 17 joined directly to the rear wall 16, and to the front wall 15 by a short sloping section 18, and side panels 19, 20 of matching configuration. The enclosure 14 forms the dishwasher cavity 22 for receipt of the dishware to be cleansed. A control knob 24 is located on the front panel 25 of the cabinet 13 and although not shown in the drawings it will be understood that the electrical and electronic control apparatus as well as a motor, pump and the like may be conveniently located in the cabinet 13 beneath the dishwasher enclosure 14 or in any other nearby location. For purposes of illustration, the dishwasher 10 is shown with a wash load including a plurality of plates 26 supported in position by a rack 27 in the lower portion of the cavity 22, a plurality of cups 28 positioned at the upper portion thereof, and a silverware basket 29 disposed near the front wall 15 of the dishwasher cavity 22. A fluid connector 31 is mounted in a depressed portion 32 of the bottom 17 of the enclosure 14 and such connector 31 may form the drain outlet and the water inlet for the transferral of the cleaning medium into and out of the dishwasher cavity 22.

A plurality of transducers 35 is mounted to lower exterior portions of the dishwasher enclosure 14 and in the description of the electrical portion of this invention, reference will be made to the utilization of six transducers. It will be appreciated that a greater or lesser number may be employed depending upon the relative efficiency required in the system, the power levels of operation and the like. Each transducer 35 is of the electrostrictive piezoelectric type consisting of a barium titanate crystal and mounting arrangement and it will be understood that other types of transducers may be employed as well under the teachings of this invention.

A cover 37 for the dishwasher cavity 22 is shown in the closed position being pivotally mounted to the top of the cabinet 13, as generally indicated at 38, and the cover 37 may be swung to the open position for access to the dishwasher cavity 22. In normal operation, the cavity 22 is filled with water as the cleaning medium to a level indicated by the dashed line 39 so as to completely submerge all of the items to be cleansed. While the particular cleaning medium and the use of detergents and the like are not of any great significance it should be understood that various loading arrangements of the dishwasher cavity 22 may have some effect upon the electronic system in requiring greater or lesser amounts of power and in varying the frequency of operation. Such loading effect, however, is believed not a contributing factor to the proper operation of this system and is readily accommodated, the only significance being the above-mentioned reflected condition imposed upon the power supply which will be described in greater detail hereinafter. While the cleaning medium is

retained within the cavity 22 during ultrasonic cleaning, it will be understood that various additional cycles of rinsing and the like may be employed throughout the complete cleaning operation.

In FIG. 3, there is shown a circuit schematic of this invention wherein a source of power 40 which may be the typical 120 volt, AC 60 Hz. household power is connected through a fuse 41 to the input terminals 42, 43 of a bridge rectifier 45. The output of the rectifier appears at terminals 47, 48 and connected thereacross are capacitors 49, 100 which provide a measure of filtering and high frequency bypass, respectively, so that essentially a DC voltage is realized for energizing the circuit. As will be pointed out in greater detail hereinafter, the DC voltage appearing at terminals 47, 48 includes a rather large ripple voltage of twice the frequency of the power source 40 and which is utilized in controlling the output frequency of the circuit.

An output transformer 50 having primary windings 51a, 51b with a center tap 52 and a secondary winding 53 is provided for converting the voltage appearing within the circuit to an optimum output voltage at terminals 54, 55 and for providing electrical isolation. A load 56, comprising six transducers 35 in parallel connection is connected across the secondary winding 53 of the transformer 50, such connection being made by lead wires extending from the area beneath the dishwasher cavity 22 to the array of transducers 35.

The electrical circuit is basically a typical inverter circuit which utilizes semiconductor components for alternately switching current through the primary windings 51a, 51b of the transformer 50 at an ultrasonic frequency. Such switched current is coupled to the transducer load 56 by the secondary winding 53 of the transformer 50 at a reduced voltage level. The primary windings 51a, 51b of the transformer are connected to lines 58, 59 respectively, the positive output terminal 48 of the bridge rectifier is connected to center tap 52 and the negative output terminal 47 is connected to ground 60 which forms a reference potential for the circuit. The switching of current through the primary windings 51a, 51b of the transformer 50 is achieved by the interconnected switching action of a pair of NPN transistors 62, 63 having respective collectors 62c, 63c connected to lines 58, 59 and emitters 62a, 63a connected through resistors 65, 66 to ground 60.

A saturable core transformer 68 is provided for achieving oscillation within the circuit and serves to couple the outputs of the transistors 62, 63 with the input circuit in a relationship suitable to achieving oscillation. The primary winding 68a of the transformer 68 is connected at each end through resistors 69, 70 of approximately 800 ohms to the collectors 62c, 63c of the transistors 62, 63, and thus, to each side of the primary windings 51a, 51b of the output transformer 50. The secondary windings 68b, 68c of the saturable core transformer include a center tap connection 72 and are wound to have the phase relationship indicated by the dots in FIG. 3. The ends of the secondary windings 68b, 68c are connected to the base electrodes 62b, 63b, of the respective transistors 62, 63, through resistors 74, 75 of approximately 10 ohms resistance. Semiconductor diodes 76, 77 are connected from the base electrodes 62b, 63b of the transistors to ground potential 60 and are poled in a direction to prevent a negative voltage from occurring at the base electrodes.

A voltage divider consisting of series resistors 78, 79 having common junction 80 and including capacitor 82, bypass capacitor 101, and diode 83 connected in parallel with resistor 79 is connected between ground potential 60 and the positive output terminal 48 of the bridge rectifier 45. The junction 80 of the voltage divider is connected directly to the center tap 72 of the secondary windings of the saturable core transformer 68 and in normal operation provides a relatively low voltage which is on the order of approximately one volt to aid in the start up of the circuit and to avoid distortion of the output waveform at the time of switching of the transistors 62, 63.

The circuit shown in FIG. 3 utilizes a parallel switching action to accommodate relatively high power levels which are on the order of approximately 750 watts of input power. The parallel circuit consists of transistors 85, 86 which are connected with identical circuitry in parallel with transistors 62, 63 respectively and which receive the switching signals from the secondary windings 68b, 68c of the transformer 68 by way of lines 87, 88. The circuit also includes a thyrector 90 which is a back to back diode element, connected across the primary windings 51a, 51b of the output transformer 50 to prevent destructive voltage transients from affecting the components of the circuit, similar action being performed by the base to ground diodes 76, 77 previously mentioned as well as diodes 91, 92.

Thus, the operation of the inverter circuit of FIG. 3 occurs as follows. Upon switching on power a slight positive potential will appear at the junction 80 of the voltage divider and will cause either transistors 62, 85 or transistors 63, 86 to conduct due to inherent variances within the circuit. It will be assumed that the potential at the base 62b of transistor 62 will be increasing in a positive direction to cause greater conduction of transistor 62 and similarly, of transistor 85. Current will flow in the conventional sense from the positive terminal 48 of the bridge rectifier 45 to the center tap connection 52 of the transformer 50, through primary winding 51a, the collector to emitter paths of transistors 62, 85, and the emitter resistors 65, 94 to ground potential 60. Current flow will also occur through the primary winding 68a of transformer 68 and due to the polarity of connection of the secondary windings 68b, 68c will serve to further increase the positive potential at the base electrodes of transistors 62, 85 until saturation occurs. In the opposite portion of the circuit, an inverse action will occur such that the bases of transistors 63, 86 will be driven in a negative sense to completely cut off collector to emitter conduction and thus the flow of current through primary winding 51b. When saturation of transformer 68 occurs and no further current change takes place, the voltage polarities at the secondary windings 68b, 68c of the transformer will reverse and all transistors will be driven in the opposite sense such that transistors 63, 86 will be driven toward saturation while transistors 62, 85 are cut off to complete the cycle.

Thus, it may be seen that the primary windings 51a, 51b of the output transformer 50 will realize current flow from the center tap 52 to either side alternately and this action will occur at a frequency dependent upon the voltage output of the bridge rectifier 45 and the saturation characteristics of the saturable core transformer 68. If the DC voltage output of the bridge rectifier 45 and filter capacitor 49 arrangement were a constant DC level, the inverter circuit would attain a nominal frequency of operation and only vary slightly from this level due to temperature effects and the like of the components within the circuit. This condition also assumes that a fixed transducer load 56 is connected across the secondary winding 53 of the output transformer 50 such that the circuit characteristic impedance will be reflected back to the transistor switching portion of the circuitry. If the load 56 were varied to some extent as by the connection of either a greater or lesser number of transducers 35 or by the variation in loading of the dishwasher cavity 22 by means of, for example, a different water level or different amounts or types of dishware therein, a corresponding slightly different frequency of operation would be expected and does occur.

Assuming, however, that all of these variables remain relatively constant, a substantially constant frequency of output voltage from the inverter circuit will be realized. As pointed out previously, when the transducer 35 are energized in such a manner ultrasonic oscillations are set up within the dishwasher cavity 22 and a static condition of distribution of energy within the cavity will prevail. Localized cleaning therefore, will occur and it will be clear that some locations within the cavity will achieve no cleaning effect due to the interference of the standing waves where nodal effects occur. It is a prime object of this invention to avoid such static wave conditions

within the dishwasher cavity to effect a more efficient cleaning operation.

It has been determined that if the input voltage to the inverter circuit at terminals 47, 48 is caused to vary about a nominal DC level, then a corresponding variation in the output frequency at terminals 54, 55 can be achieved.

Referring now to FIG. 4, it is shown that such a frequency variation occurs in the output of the circuit, even though the reasons for the circuit performance are not well understood at this time. FIG. 4 is a graph of the output frequency of the inverter circuit at the secondary winding 53 of the output transformer 50, for a typical load 56 configuration as that previously described, as the DC volts applied at terminals 47, 48 of the circuit are varied. A dashed line 95 is depicted on the graph and is indicative of the transducer-load resonant frequency which in this example will be assumed to be at a frequency of 25 kHz. As the DC level of voltage at terminals 47, 48 is increased in a positive sense, the frequency of operation of the circuit will increase also in an approximately linear manner as shown generally at 96. This would be expected output variation from typical inverter circuit theory.

As the output frequency reaches a level of approximately 20 kHz., a snap shift in frequency occurs as indicated at 98, such that the frequency of operation suddenly shifts toward the load resonant level 95 without any further increase in the input DC voltage. This snap shift 98 in frequency might also be expected in a circuit configuration of this type wherein a particular load arrangement has a relatively defined natural frequency of resonance. When the load 56 and circuit frequencies become relatively close, it would be expected that one would "lock" onto the other or that a new frequency of resonance for the combination might be expected. Along this line of reasoning, it should be assumed that further variations in the DC input voltage would cause relatively little frequency deviation in the output voltage since the combination would tend to maintain the resonant frequency of operation.

However, it has been determined that input voltage variations will create a corresponding output frequency variation as indicated by line 99 showing both an increase and decrease of output frequency as the DC volts are varied about the snap shift level. This deviation from a nominal level is a desirable attribute of this circuit in altering the ultrasonic frequency realized from the transducers 56 and thus varying the standing wave pattern within the cleaning cavity to effect a thorough cleaning operation.

Such input DC voltage variation is readily achieved in this particular circuit since an alternating current power source 40 is utilized. It is well known that the output of the bridge rectifier 45, without filtering, is a full wave DC voltage varying in amplitude as the voltage of the AC source varies. In typical power supply circuits, it is usual to provide a filter to smooth this voltage completely to avoid ripple which is normally not desirable. Here, however, the ripple voltage provides a voltage variation at terminals 47, 48 to alter the output frequency applied to the transducers and this is readily provided by a minimal filter arrangement consisting, in this embodiment, of a 200 mfd. condenser for capacitor 49, bypass capacitor 100 being on the order of 0.1 mfd. This circuit is designed so that the ripple voltage present at the output of the bridge rectifier 45 is about 10 percent of the value of the voltage level that results in operation at transducer resonance. A 5 percent frequency shift is achieved for such a 10 percent voltage change.

Although AC voltage as the power source 40 provides a convenient signal for varying the DC voltage at terminals 47, 48, it will be appreciated that such variations could be effected differently as by modulating the voltage by a locally

generated signal. Similarly, different transducer-load configurations and modifications of the circuitry are possible while still realizing the "sweep" frequency output feature of the described arrangement. Further, component values, frequency and power levels specified herein relate to the preferred embodiment and may be varied for different applications.

Other modes of applying the principles of the invention may be employed, change being made as regards the details described, provided the features stated in any of the following claims or the equivalent of such be employed.

I, therefore, particularly point out and distinctly claim as my invention:

1. In combination with a load device, apparatus for producing ultrasonic vibrations in said load device at continuously varying frequencies, comprising a plurality of transducers coupled to said load device, said transducers being in parallel electrical connection and operative to convert electrical energy to mechanical vibrations, an output transformer having a secondary winding connected to said transducers and a primary winding adapted for energization, a first pair of switching elements connected to said primary winding for controlling current flow therein, a second pair of switching elements operatively connected in parallel with said first pair of switching elements, a saturable core transformer operatively connected with said switching elements for alternate energization thereof, the primary winding of said saturable core transformer being operatively connected with the primary winding of said output transformer, the frequency of alternation being dependent upon the magnitude of voltage applied to said switching elements, means for supplying DC voltage to said switching elements for energizing same at a nominal frequency of alternation, and means for effecting cyclical variations in the DC voltage to cause variations in the frequency of alternations.

2. The combination set forth in claim 1 wherein said switching elements comprise transistors having collector electrodes connected to the primary winding of said transformer and adapted for energization from said saturable core transformer.

3. An ultrasonic dishwasher, comprising a housing forming an enclosure for receipt of dishware and the like and a fluid medium, a plurality of piezoelectric transducers mounted on the exterior of said housing for generating ultrasonic vibrations in the fluid medium contained therein, an inverter circuit for energizing said transducers, said circuit having a nominal frequency of operation in the ultrasonic frequency range and comprising an output transformer having a secondary winding connected to said transducers, a first pair of transistors having collector electrodes connected to the primary winding of said transformer, a second pair of transistors operatively connected in parallel with said first pair of transistors for energizing the primary winding of said transformer, and a saturable core transformer having a primary winding operatively connected to said collector electrodes and a secondary winding operatively connected in the base-emitter paths of said transistors, and means for energizing said inverter circuit with a DC voltage having a high ripple voltage, comprising an AC power source, a rectifier, and filter capacitor combination, said filter capacitor having a capacitance value to provide approximately 10 percent ripple voltage, whereby said transducers will provide ultrasonic vibrations in the fluid medium at frequencies continually varying about such nominal frequency.

4. A dishwasher as set forth in claim 3 wherein said rectifier is a bridge rectifier, said power source is 60 cycle alternating current and the frequency of the ripple voltage is 120 cycles per second.