

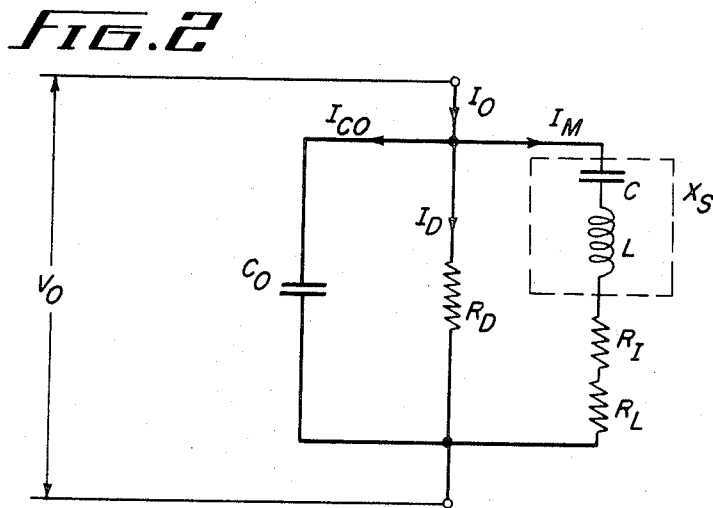
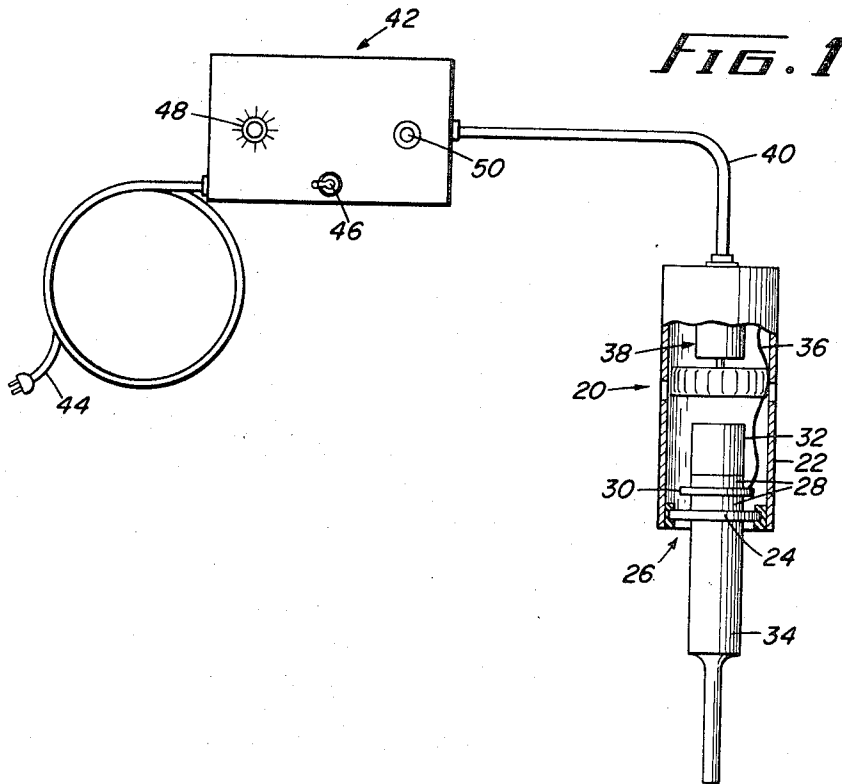
Sept. 1, 1970

A. SHOH
APPARATUS FOR CONTROLLING THE POWER SUPPLIED TO AN
ULTRASONIC TRANSDUCER

3,526,792

Original Filed Dec. 8, 1964

3 Sheets-Sheet 1



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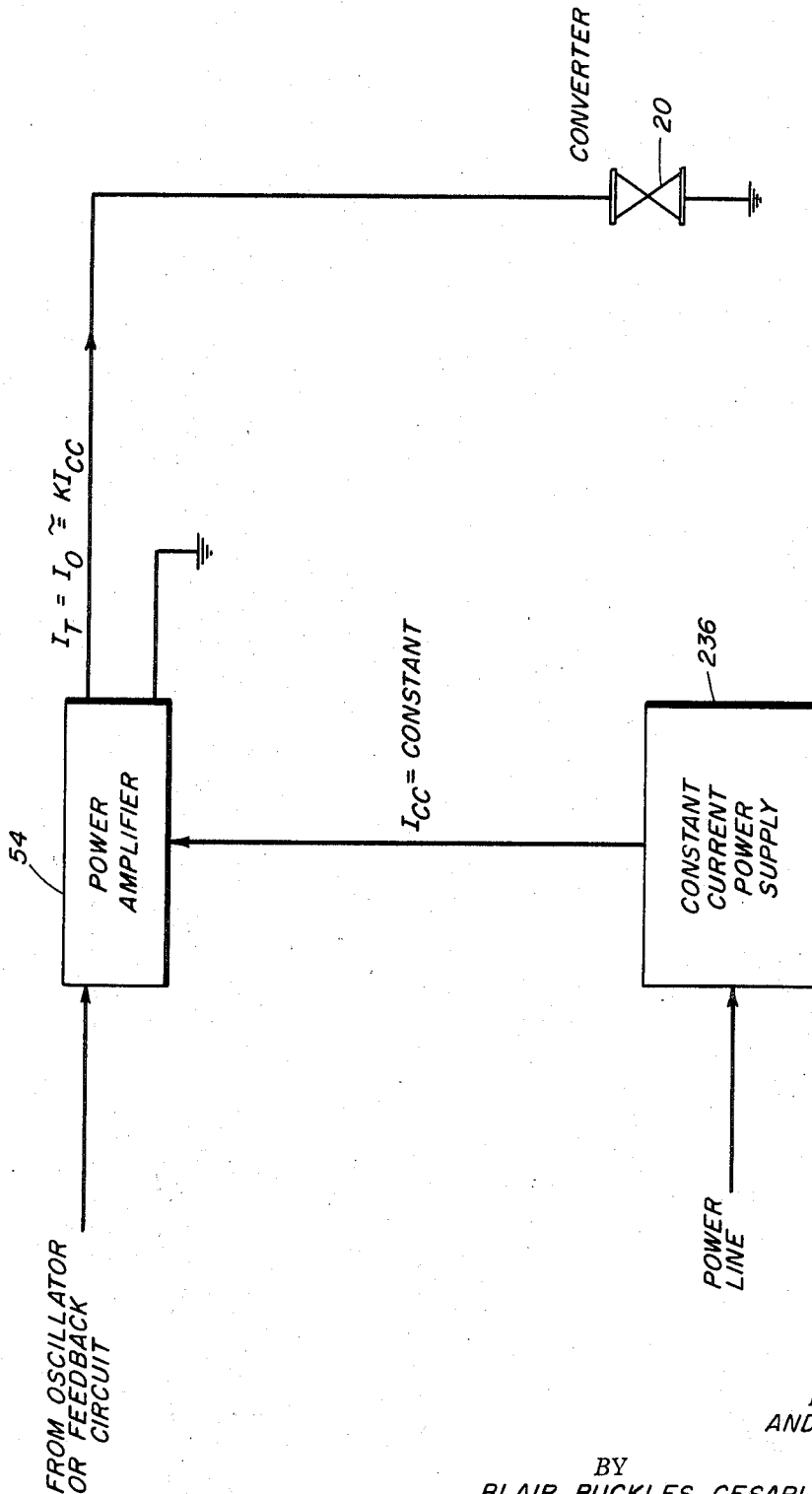


FIG. 3

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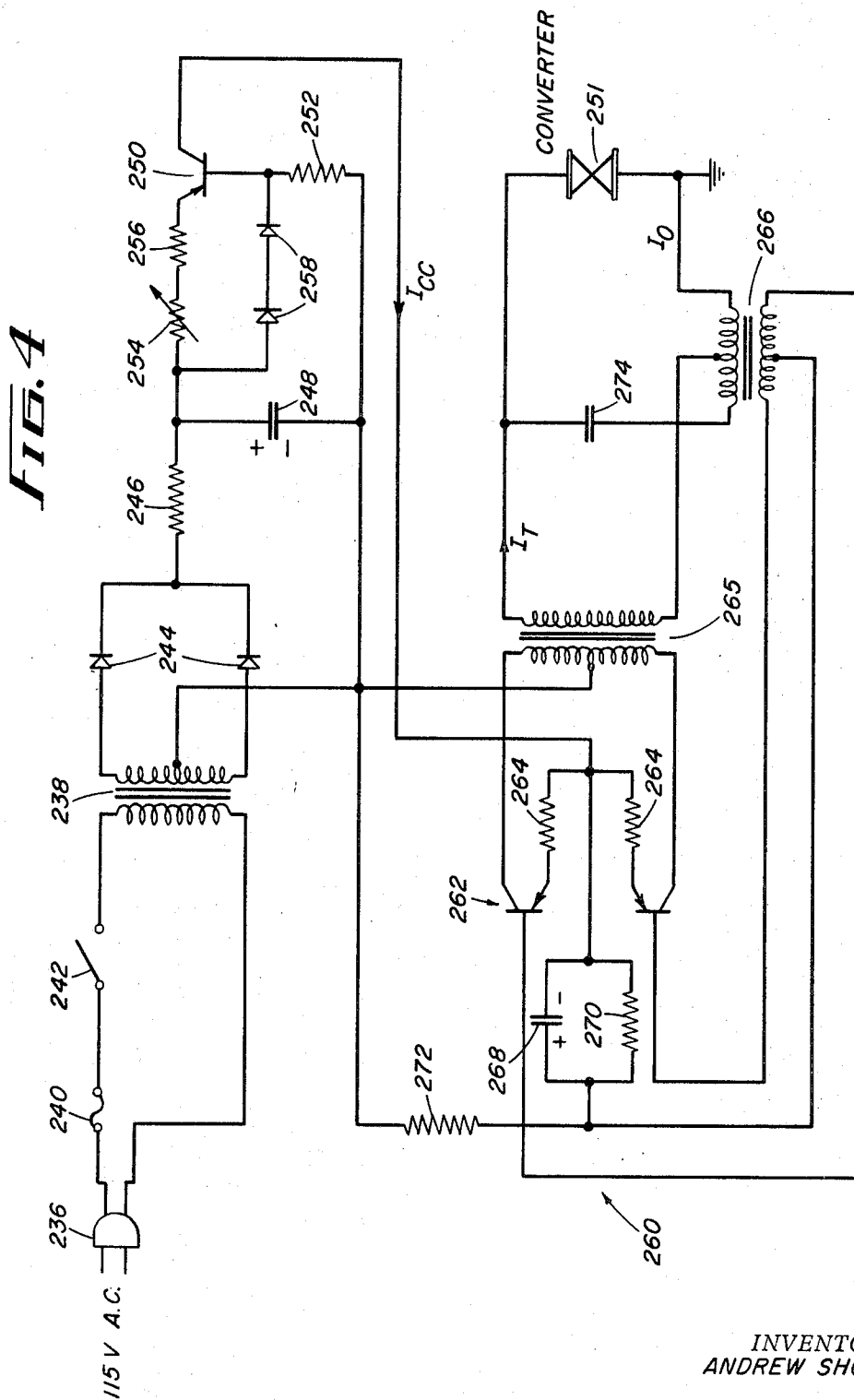
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APPARATUS FOR CONTROLLING THE POWER SUPPLIED TO AN ULTRASONIC TRANSDUCER
Andrew Shoh, Ridgefield, Conn., assignor, by mesne assignments, to Branson Instruments, Incorporated, Stamford, Conn., a corporation of Delaware
Application Dec. 8, 1964, Ser. No. 416,816, now Patent No. 3,443,130, dated May 6, 1969, which is a continuation-in-part of application Ser. No. 265,751, Mar. 18, 1963. Divided and this application Apr. 26, 1968, Ser. No. 724,454

Int. Cl. H01v 7/00

U.S. Cl. 310—8.1

4 Claims

ABSTRACT OF THE DISCLOSURE

The disclosed apparatus includes a constant current source supplying constant current to a piezoelectric ultrasonic transducer. This constant current supply causes the motional current through the transducer to remain likewise constant despite variations in the acoustical load to which the transducer is coupled. The magnitude of the constant supply current is established at a level which the transducer can safely dissipate when lightly loaded. As the load increases, the power coupled thereto likewise increases automatically.

REFERENCE TO RELATED APPLICATIONS

This application is a divisional application of my copending application Ser. No. 416,816 filed Dec. 8, 1964, entitled Sonics, now U.S. Pat. 3,443,130; which is in turn a continuation-in-part of my application Ser. No. 265,751, filed Mar. 18, 1963, entitled Ultrasonic Cleaning Apparatus, now issued as Pat. No. 3,293,456.

BACKGROUND AND OBJECTS OF THE INVENTION

In recent years sonic energy has found wide use in science and industry for cleaning, soldering, welding, material treatment, homogenizing, dispersing, microbiological cell disruption and the like. For many years both magnetostrictive and electrostrictive (piezoelectric) transducers have been used in sonic cleaning systems. Magnetostrictive transducers utilize metal laminated core structures that change in length when subjected to a magnetic field provided by a coil. Electrostrictive or piezoelectric transducers utilize crystalline or ceramic elements that change their length under the influence of an applied electric field. Except for the above-mentioned use in cleaning tanks, up until a few years ago, the vast majority of sonic transducer systems for providing high sonic power levels were of the magnetostrictive type. However, the development of piezoelectric ceramics, such as lead titanate, lead zirconate, capable of withstanding the high temperatures developed in high powered transducer systems have led to their use in high power general purpose systems. Such a general purpose transducer system or sonic converter is disclosed in U.S. Pat. No. 3,328,610, issued to Stanley E. Jacke and Henry Biagini.

In the above identified application the sonic vibrations developed electrostrictively in a pair of ceramic wafers are concentrated and increased in amplitude by a concentrating horn or acoustic impedance transformer to provide at the end thereof extremely high power densities per unit area. This sonic converter is being used in many of the ultrasonic process applications listed above, for example, for homogenizing, dispersing and disrupting biological cells, in ultrasonic welding, soldering and treatment of materials and the like.

As discussed in the above identified copending applica-

2

tion, one of the problems encountered in operating such a high power sonic converter is that when the device is energized and the tip of the concentrating horn is not coupled to any medium other than air the tip vibrates violently at very large amplitudes. Very little power is transferred to the air and substantially all of the power supplied to the converter must be dissipated therein. In contrast therewith, when the tip of the concentrating horn is coupled to a less compliant medium, such as a liquid, energy transfer occurs from the horn to such a medium, thus leaving a smaller amount of energy to be dissipated in the converter. Depending upon the efficiency of the converter, the medium which receives the acoustic power and the degree of coupling achieved, the power to be dissipated in the converter may vary over a ratio of 10 to 1 from the condition of no power transfer to the load, to the other condition when good power transfer from the horn to the load is achieved.

In order to protect the transducers from the possibility of destruction by excessive power dissipation, the prior art employed principally two approaches. One method is to limit the power supplied to the converter to the amount of power which the converter safely can dissipate under the condition of no power transfer. As is readily apparent, this approach seriously limits the power which is available to the converter when good power transfer between the horn and the load is achieved. The other approach concerns the provision of manually adjustable power control means, for instance, selectable voltage levels in order to vary the power supplied to the converter. This latter method, as is readily apparent, is not satisfactory as the operator must judge the degree of power transfer and, in the event that too much power is applied to the converter, or if the converter is uncoupled from the load and inadvertently left to operate into air without power reduction, the converter may destroy itself.

As a consequence of these problems, converters of this type have been generally limited to low power levels. For example, the converter disclosed in the above identified copending application has been limited to a maximum of approximately 100 watts; this being the greatest power the converter can internally dissipate when operating in air. Generally speaking the greater the impedance of the acoustic load presented to the converter the smaller the power supplied to the medium.

Methods, apparatus and systems have been discovered, as disclosed in copending application Ser. No. 416,816, for controlling the power supplied to a converter. In order to better understand the instant invention the following observation has been made utilizing an S-75 converter manufactured by Branson Sonic Power Division of Branson Instruments, Inc. in Danbury, Conn. The Branson S-75 converter was connected to a power amplifier to form an oscillator in the manner described in the above-identified Pat. No. 3,293,456. As explained therein, it thus operated at the frequency of maximum conversion efficiency. The converter using a solid step horn acoustic transformer was operated first in air. Various voltages were supplied to the converter. The amplitude of the motion of the tip of the concentrating horn and the motional current supplied to the converter were measured. The motional current was derived in the manner described in the above identified copending application. That is, a current equal to the clamped capacitance current of the converter was subtracted from the total current supplied to the converter. This produces a current equal to the motional current in the series branch equivalent circuit of the converter.

It was found that the motional current supplied to the converter and the amplitude of the motion of the tip

of the concentrating horn were directly proportional throughout the useful operating range of the converter. It was further found that this proportionality was independent of the acoustic load presented to the transducer when the transducer was operated in air, water or heavy oil.

It was further found by driving the converter with a variable frequency oscillator that this proportionality was substantially independent of frequency at or near the natural resonance of the transducer.

It was further found that the internal dielectric losses of the converter were small and may be neglected. Furthermore it was found that the internal losses in the converter appear to the driving generator or amplifier as a substantially constant impedance in series with a varying impedance directly proportional to the acoustic load presented to the converter.

It is therefore an object of the present invention to provide apparatus for keeping the heat dissipation in a sonic converter constant or below a predetermined maximum.

A further object of the invention is to provide apparatus for keeping the amplitude of the motion of the transducing elements of a sonic converter constant or below a predetermined maximum.

Still another object of the invention is to provide apparatus for keeping the power dissipated in a sonic converter constant or below a predetermined maximum.

A still further object of the invention is to provide apparatus for keeping an electrical quantity supplied to a sonic converter proportional to the quantities of the above objects constant or below a predetermined maximum.

Still another object of the invention is to provide apparatus for keeping motional current supplied to an electrostrictive sonic converter constant or below a predetermined maximum.

Another object of the invention is to provide automatic apparatus for increasing the total power supplied to a sonic converter as the acoustic impedance into which the converter is working increases.

Still another object of the invention is to provide apparatus for keeping the total current supplied to a sonic converter employing electrostrictive elements substantially constant or below a predetermined maximum.

A further object of the invention is to control the power delivered to an ultrasonic transducer.

Another object of the invention is to compensate for the varying acoustic impedances into which an ultrasonic power transducer operates.

Other objects of the invention will in part be obvious and will in part appear hereinafter.

The invention accordingly comprises the several steps and the relation of one or more of such steps with respect to each of the others and the apparatus and systems employing features of construction, combinations of elements and functions, and arrangements of parts which are adapted to effect such steps, all as exemplified in the following detailed disclosure. The scope of the invention will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention reference should be had to the following detailed disclosure taken in connection with the accompanying drawings in which:

FIG. 1 is a front view, partially cut away, of an ultrasonic power converter and electronic driver in accordance with the present invention.

FIG. 2 is an equivalent circuit of the ultrasonic power converter shown in FIG. 1.

FIG. 3 is a block circuit diagram of the present invention.

FIG. 4 is a detailed circuit diagram of the invention shown in FIG. 3.

The same reference characters refer to the same elements throughout the several views of the drawings.

GENERAL DESCRIPTION

The ultimate objects of the present invention are to limit the dissipation in a sonic converter to a safe, maximum value for all loading conditions and to obtain a loading characteristic wherein the mechanical power output from the converter increases when the converter operates into a load of increased acoustical impedance.

The ultimate objects of the invention are realized by providing means in a power generator connected to the converter such that the total current supplied to the converter is substantially constant as the converter operates into varying acoustic impedances. This is achieved according to the invention by making the power generator a constant current source.

SPECIFIC DESCRIPTION

Now referring to FIG. 1, a high power density ultrasonic converter is generally indicated at 20. This is constructed in the manner detailed in the above noted U.S. Pat. No. 3,328,610. The converter 20 comprises a metal casing 22 supporting a perforated metal vent plate 24 integral with the transducer system generally indicated at 26. The transducer system is bolted together and comprises a pair of ceramic discs 28 separated by a metal plate 30. The ceramic discs 28 are backed by a massive metal back plate 32 and operate into a sonic energy concentrating step horn 34. Electrical energy is supplied to the transducer system 26 by means of a wire 36 connected to the metal plate 30 and the metal casing 22 connected to the vent plate 24. The converter also comprises a fan 38 for cooling the transducer system 26.

Power for the transducer system 26 and the fan 38 is supplied via an insulated cable 40 from a power generator generally indicated at 42. The power generator 42 is connected via line cable 44 to a supply of 115 volts, 60 cycle power.

The converter 20 may be turned on by means of an on-off switch 46 or by means of a foot switch (not shown) which alternatively may be in series with the on-off switch 46. A power level control 50 may also be provided.

The experiments discussed in the introduction above indicate that at a given operating frequency the converter 20 may be represented by the equivalent circuit shown in FIG. 2. This circuit comprises a clamped capacitance C_0 representing the load independent capacitance of the converter. The clamp capacitance C_0 is in parallel with a resistance R_D representing the dielectric or voltage dependent losses in the converter.

A third parallel arm of the equivalent circuit comprises a frequency dependent reactive impedance X_S which may be represented by the series connected capacitance C and inductance L . The resistance R_I represents the internal motion dependent losses in the converter. The resistance R_L represents the transformed acoustical impedance of the load into which the converter 20 is operated. The resistance R_L has been found to be directly proportional to the acoustical impedance of the load over the useful operating range of the converter 20. The resistance R_I , which represents the motion dependent internal losses, has been found to be substantially constant over the useful operating range of the converter 20.

When a Branson Sonifier S-75 converter is operated at 20 kHz. with a 1½ inch probe terminated by a step horn, R_I is found to be approximately 100 ohms. R_L when the converter operates into air is substantially zero. When the converter is loaded, R_L may be as high as several thousand ohms. R_D has been found to be comparatively large and can therefore be neglected. C_0 is approximately .0038 microfarad.

Thus, when operating at resonance and from a constant voltage source, the current I_{C_0} through the clamped capacitance C_0 is constant. The current I_D through the dielectric resistance R_D is substantially zero. The mo-

tional current I_M is substantially dependent on R_L , since R_T is constant and at resonance, the reactive impedance X_S is zero.

The total current I_O supplied to the converter may be vectorially added to the current passing through a capacitor having a value of .0038 microfarad connected across the source of the voltage V_O supplying the converter to derive the motional current I_M . Methods for doing this are disclosed in detail in the above identified U. S. Pat. No. 3,293,456.

As disclosed therein, the derived motional current I_M supplied to the converter may be utilized to provide a positive feedback signal for a power amplifier in the power generator 42 to cause the entire circuit to oscillate and thus the converter to operate at the natural mechanical resonance of the converter.

When the motional current I_M is kept constant the amount of power delivered by the converter into a load will depend solely on the acoustic impedance of the load. That is as the acoustic impedance of the load increases, R_L increases and the load dissipated power $I_M^2 R_L$ will increase. At the same time the internal motional losses in the converter $I_M^2 R_T$ will remain constant.

To obtain constant motional current I_M , sonic power generator means having a constant current source characteristic is employed in accordance with the invention shown in FIG. 3. There the power amplifier 54 is supplied from a constant current power supply 236 connected to the power line. Constant current power supply 236 produces a constant power supply current I_{CC} to the power amplifier 54 and, as is well known to those skilled in the art, if the drive is always sufficient to saturate the amplifier, this will cause the output current I_O supplied to the converter 20 to be substantially constant. As long as the output current I_O is maintained constant, the motional current I_M will also remain substantially constant, for a wide range of converter loading conditions. The power amplifier may be driven from an oscillator or a feedback circuit as has been described in copending application Ser. No. 416,816 and U.S. Pat. No. 3,293,456.

A detailed circuit operating in the manner shown in FIG. 3 is shown in FIG. 4. Now referring to FIG. 4, line plug 236 is connected to a source of 115 volt, 60 cycle A.C. Power is supplied to the power supply transformer 238 through a fuse 240 and a switch 242. The secondary of transformer 238 is center tapped. The secondary produces 50 volts A.C. across rectifiers 244, both type 1N2071. They are connected to a filter network comprised of a 5 ohm resistor 246 and a 100 microfarad capacitor 248 in the well known manner.

The constant current characteristic to keep the output current I_T of the power supply constant is obtained by connecting a transistor 250 type 2N350A in the power supply circuit, in the manner shown. By means of resistor 252 and diodes 258 the bias across the serially connected variable resistor 254, fixed resistor 256 and the base to emitter junction of transistor 250 is fixed in accordance with the forward voltage drop across diodes 258. The transistor emitter current through resistors 254 and 256, substantially equal to the transistor collector current, will adjust itself such that the voltage drop across the serially connected resistors 254 and 256 is equal to the reference voltage across diodes 258 less the relatively low and constant voltage drop across the base to emitter junction of transistor 250, thus making the collector current I_{CC} substantially constant and independent of the loading presented to the power supply.

Resistor 252 is 470 ohms, variable resistor 254 has a maximum resistance of 5 ohms and resistor 256 is 1 ohm. Diodes 258 are each type 1N2071.

The adjustable resistor 254 is typically set to a value which will yield an average D.C. collector current I_{CC} of approximately .6 ampere. The amplifier 260, which is driven from the power supply, is a 10 watt self-tuning

amplifier for use with a converter 251 used in micro-biological cell disruption, and the like, where only low power total power levels are desired. The amplifier comprises a single push-pull stage comprising two transistors generally indicated at 262, these are type 2N1905. The emitters of transistors 262 are connected through 1 ohm resistors 264 to the collector of transistor 250. The collectors of transistor 262 are connected across the primary of an output transformer 265. The bases of transistors 262 are connected across a center tapped secondary of an input current transformer 266. The center tap of the current transformer 266 is connected through a 10 microfarad capacitor 268 and a 68 ohm resistor 270 to the collector of transistor 250. The center tap of current transformer 266 is also connected to the other side of the power supply through a 1 kilohm resistor 272. The center tap of output transformer 265 is also connected to this common terminal of the power supply.

The secondary of output transformer 265 is connected in circuit with the converter 251 and one-half of the primary of current transformer 266. It is also connected in circuit through a compensating capacitor 274 and the other side of the primary of current transformer 266. The converter 251 has a clamped capacitance of .002 microfarad and therefore the compensating capacitor 274 has the same capacitance. The inductance of the secondary of the output transformer 265 is selected to resonate with .004 microfarad which is the sum of the converter clamped capacitance and the compensating capacitor 274. The primary of transformer 266 comprises 8 turns, center tapped. The secondary comprises 16 turns, center tapped. The primary of output transformer 265 comprises 30 turns, center tapped and the secondary also comprises 30 turns.

It will be seen that the input signal applied to the transistors 262 from the secondary of transformer 266 is representative of the motional current I_M in the converter 251 and the circuit therefore operates at the frequency of maximum conversion efficiency of the converter. The output current I_T of transformer 265 will be substantially constant as will the current I_O supplied through the converter. This is due to the constant current operation of the amplifying transistors 262.

It will thus be seen that the objects set forth above, among those made apparent from the preceding description, are efficiently attained and, since certain changes may be made in the above construction without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described, and all statements of the scope of the invention, which, as a matter of language, might be said to fall therebetween.

What is claimed is:

1. Apparatus of the class described comprising:

(A) an electroacoustic sonic converter having at least one electrostrictive element; and

(B) a constant current sonic power generator means connected in driving circuit with said converter,

(1) the current through said converter being essentially equal to the constant current output of said generator,

(2) whereby the current through said converter is substantially independent of the converter acoustical load.

2. The combination defined in claim 1 wherein said constant current sonic power generator comprises:

(1) a power amplifier, and

(2) a constant current power supply for said power amplifier.

3. The combination defined in claim 2 which further includes:

(C) a feedback circuit supplying a control signal to said power amplifier corresponding to the motional current in said converter for controlling the frequency of the constant current supplied to said converter.

4. The combination defined in claim 3, wherein:

(1) said power supply includes

(a) electronic valve means, and

(b) means for developing a constant bias to maintain the current through said valve means constant, and

(2) said feedback circuit includes:

(a) a capacitor connected across said converter, and

(b) a summing transformer having a primary winding connected in circuit with said capacitor and said converter for deriving a current proportional to the motional current through said converter and a secondary winding connected to supply said control signal to said power amplifier.

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