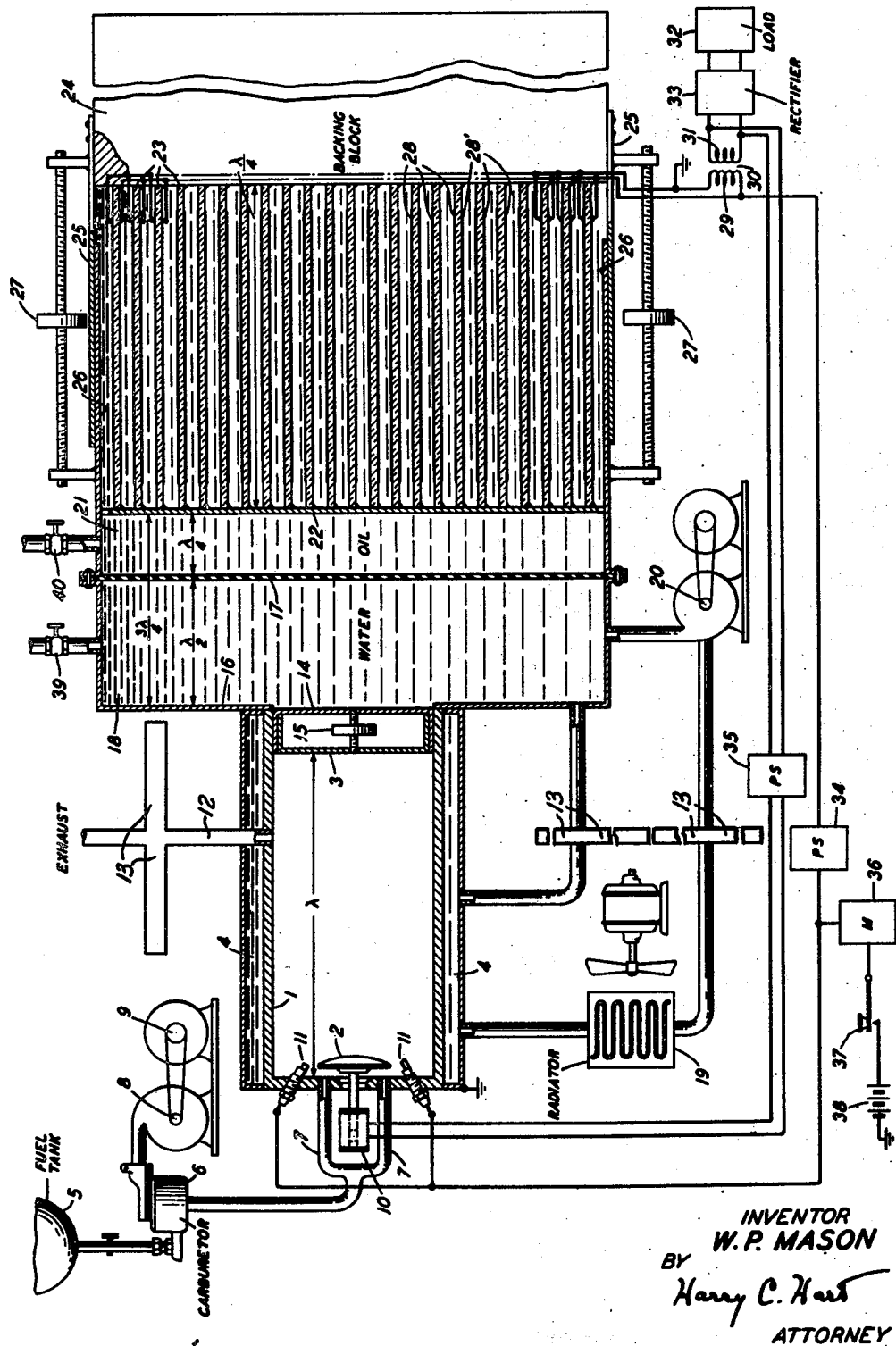


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INVENTOR
W. P. MASON
BY
Harry C. Hart
ATTORNEY

UNITED STATES PATENT OFFICE

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ELECTRIC POWER SOURCE

Warren P. Mason, West Orange, N. J., assignor to
Bell Telephone Laboratories, Incorporated, New
York, N. Y., a corporation of New York

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This invention relates to prime sources of energy and more particularly to a novel system for producing electrical energy in which an electro-mechanical transducer is excited by mechanical vibrations of an internal combustion device.

An object of the invention is to produce electrical energy by causing successive explosions of a combustible vapor or powdered fuel to induce vibrations in a vibratory electrical generator.

Another object of the invention is to convert the energy of burning fuel into electrical energy with relatively little displacement of mechanical masses and without the use of rotating parts or elements of considerable mass.

Still another object of the invention is to utilize the energy of a high frequency series of explosions to excite a piezo-electric element, a magnetostrictive element or other electro-mechanical transducer.

Another object is to provide a compression wave impedance transformer which shall be capable of transforming a very low source impedance to match a very high receiver impedance, or vice versa, without introducing losses into the system.

In accordance with the invention a vessel or chamber, in which explosions of a suitable fuel take place in rapid sequence, is so proportioned as to support sustained gas pressure oscillations or standing waves therein and the vibratory mechanical energy of these oscillations is transferred, preferably by way of a novel impedance-matching device, to a mechanical-electrical transducer element of appropriate type. This element, when actuated directly or indirectly by the oscillatory mechanical energy of the explosions, develops electrical energy which may be withdrawn and utilized to supply a desired load.

It is a feature of the invention that the main chamber in which the explosions take place is resonant or reverberant at the explosion frequency or a harmonic multiple thereof, so that pressure oscillations of large amplitude may be sustained with the addition of a comparatively small additional amount of explosive energy during each operating cycle.

It is another feature of the invention that the major portion of the oscillator pressure energy within the explosion chamber is transferred, directly or indirectly, to the mechanical-electrical transducer, means being provided to prevent its escape with exhaust combustion products.

The invention in its various aspects will be more fully understood from the following detailed description of a preferred embodiment thereof,

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taken in conjunction with the appended drawing, the single figure of which shows a sectional diagram of the apparatus and a schematic diagram of the associated electric circuit of an engine for converting explosive mechanical energy into electrical energy of like frequency.

Referring now to the figure, an explosion chamber 1 is provided, closed at one end by a valve 2 and at the other by a light, stiff, movable piston 3. The chamber walls may be of any suitable strong, pressure-supporting material such as steel or cast iron. The chamber may be surrounded by a water jacket 4 for cooling purposes. Fuel, for example in the form of atomized liquid fuel, is supplied to the chamber from a fuel tank 5 by way of a carburetor 6, an intake manifold 7 and the intake valve 2, being forced in by a supercharger pump 8, driven by a motor 9. These elements may all be of conventional mechanical design. The valve 2 is preferably operated electromagnetically as by a solenoid 10 to which energy is supplied from an electric circuit whose details will be described hereinafter. Ignition of the atomized fuel may be effected by spark-gaps 11, likewise supplied from the electric circuit, in proper phase relation with the opening and closure of the intake valve 2. Combustion products may be withdrawn by way of an exhaust pipe 12 which is preferably provided with one or more filters 13 as more fully described below.

At the end of the explosion chamber 1 opposite to the head end in which the intake valve 2 and the spark-gaps 11 are mounted there is fixedly mounted a light flexible piston diaphragm 14, for example, of sheet metal, whose peripheral skirt may be fixed as by welding to the inside walls of the chamber 1. The piston 3 may likewise be a light, flexible diaphragm whose peripheral skirt is arranged to slide, over a short distance, within the skirt of the diaphragm 14. The separation between the piston diaphragm 14 and the piston diaphragm 3, and therefore the position of the latter relative to the head end of the chamber 1 may be adjusted as by a turn buckle 15. These two diaphragms together form a partition of adjustable length between the explosion chamber 1 and a second chamber 16, which is preferably of larger cross-section than the explosion chamber. This second chamber 16 is filled with a wave-supporting liquid such as water or oil. A partition, for example, a thin sheet 17 of rubber or the like, divides this second chamber into two parts. One part, shown in the figure to the left of the partition, is filled with water 18 which may be circulated through it and through the ex-

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plosion chamber water jacket 4 and a cooling radiator 19 of a conventional design. Circulation may be effected by a pump 20 driven by a motor and the radiator 19 may be cooled by a fan.

The other portion of the second chamber 16, showing the figure to the right of the partition 16, may be filled with oil 21 which is protected from the heat of the explosions in the explosion chamber 1 by the cooled water 18 in the first portion of the second chamber 16.

A stiff, rigid member, such as an aluminum plate 22, is movably mounted in the second chamber 16 at the end remote from the explosion chamber 1. Its periphery fits loosely between the chamber walls so that oil pressures on either side of it are equalized.

Fixed as by a suitable cement to the other side of this plate 22 are the ends of a number of piezoelectric crystal elements 23 whose opposite ends are similarly fixed to a massive backing block 24. The block 24 may be mounted on and supported by a skirt 25, movably engaging with a skirt 26 which may be an extension of the outer walls of the chamber 16. The assembly comprising the backing block 24, the crystals 23 and the aluminum plate 22 and the skirt 25 may be moved bodily toward or away from the explosion chamber 1, correct positioning being effected as by turn buckles 27. With this construction the piezoelectric crystal elements are immersed in a protective bath of oil.

The piezoelectric crystal elements 23 may be cut from any suitable mother material, for example, ammonium dihydrogen phosphate (ADP) to vibrate in their fundamental longitudinal vibration mode. This material and the manner in which it should be cut are described and claimed in United States Patent to Mason 2,450,010, issued September 28, 1948. The crystal lengths may be substantially one-quarter of the wavelength of a compression wave in the crystal material. Each one is provided on either side with a conducting plate or film 28, 28' which serves as an electrode in accordance with known principles of construction and operation. Corresponding electrodes 28 may be connected electrically in parallel and to one terminal of primary winding 29 of a transformer 30, the other terminal of which may be connected to the corresponding oppositely located crystal electrodes 28'. For simplicity and convenience of illustration, the electrodes which are specific to only a few of said crystal elements are shown so connected to the primary of transformer 30, it being understood that similar electrodes of the other crystal element may be similarly connected, as indicated. The secondary winding 31 of the transformer 30 may be connected to supply a desired load 32 and, if direct current is desired, a rectifier 33 of conventional design may be interposed.

To control the timing of the ignition of the combustible mixture, a portion of the electric energy output from the crystals 23 may be fed back, by way of an adjustable phase controlling device 34, to the spark-gaps 11. Similarly, to control the timing of the intake of the combustible fuel mixture, a portion of the generated energy may be fed back, for example, from the secondary winding 31 of the transformer and by way of another adjustable phase controlling device 35 to actuate the valve solenoid 10.

Any suitable starting arrangement may be employed, for example, magneto 36, energized

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by a manually operated switch 37 and battery 38, which places a suitable voltage on the high tension electrodes of the spark-gaps 11. This voltage must, of course, be sufficiently high to cause the spark to jump the gaps 11.

The dimensional arrangements of the invention will be better understood after the description of operation of the device which ensues.

The operation of the system is as follows:

Assume that a charge of combustible vapor or fuel mixture has been drawn into the chamber by way of the intake valve 2 and that the latter has just closed. A spark is now caused to take place at the spark-gaps 11 which ignites the fuel and sets off an explosion, causing a high pressure to exist in the head end of the chamber, shown in the figure as the left-hand end. This condition of high pressure travels lengthwise of the chamber at a speed equal to the velocity of sound in the hot gas, which is approximately 1200 feet per second. The condition travels in the form of a substantially plane wave because wave travel in other modes is attenuated in the manner hereinafter described.

The high pressure condition reaches the stiff piston-diaphragm 3 and is there reflected without alteration of phase and returns toward the head end of the chamber. The reflection takes place at the piston surface after the lapse of one-half of the operation cycle. At this instant the pressure at the head end of the chamber has the lowest value it reaches during a cycle. Therefore, at or about this instant, the intake valve 2 is caused to open once more and a new charge of fuel is driven in by the pump 8 which should provide a pressure in excess of the pressure which obtains in the explosion chamber at this instant. At the instant that the pressure wave reaches the head end of the explosion chamber on its return path after reflection, i. e., after completion of a full cycle of operation, the intake valve 2 will have again closed and another spark is caused to take place at the spark-gaps 11. Thereupon the full cycle is repeated.

In order that each explosion shall take place at the instant when the pressure wave due to the prior explosion shall have returned, after reflection at the piston-diaphragm 3, to the head end of the explosion chamber, the chamber should be substantially one-half wavelength long, or a multiple thereof. When this is the case, regions of greatest oscillatory pressure will exist at the two reflecting end faces. Because, at the high frequencies contemplated in this invention, one-half wavelength might result in dimensions which are awkwardly small, a number of half wavelengths may be preferable. Thus, with a velocity of propagation of sound of 1200 feet per second and a frequency of 5000 cycles per second, the full wavelength is about 0.24 feet or about 7.3 centimeters. With a chamber which is a full wavelength long, operation is the same as above described for a half wavelength chamber, except that there will exist a velocity node or high pressure region at the central plane. The exhaust pipe 12, which should be located at a pressure node, should in this event be placed one-quarter of the chamber length from either end, as shown in Fig. 1. With a half wavelength chamber the exhaust may be centrally located.

By proper dimensioning of the quarter-wavelength crystals 23 in accordance with well-known principles they may be made resonant at a desired operating frequency, for example, 5000

cycles per second or a multiple thereof. Precise adjustment of the length of the explosion chamber and so of the wavelength of sound in the gaseous mixture, which depends on its temperature, to match the natural frequency of the crystals 23 may be effected in any desired manner, for example, by adjustment of the position of the reflecting piston-diaphragm 3 by the turn-buckle 15.

In order to prevent the vibration of the gas column in the explosion chamber at higher modes and restrict its energy so far as possible to the energy of plane waves, it suffices properly to restrict the cross-section of the chamber. Thus, higher modal oscillations will be rapidly damped out if the chamber diameter, assuming it to be of circular section, be less than 0.6 times the wavelength, or in this case, 4.3 centimeters. It is advisable to introduce a small factor of safety and use a figure of about 0.5, in practice. This sets an upper limit of 3.6 centimeters to the diameter of the explosion chamber. For an explosion chamber of rectangular cross-section the corresponding criterion is that the shorter side of the cross-section should not exceed one-half wavelength. The considerations out of which this design criterion arises are fully explained in "Electromechanical Transducers and Wave Filters" by W. P. Mason (Van Nostrand, 1942) at pages 108 to 110.

As stated above, the exhaust pipe 12 should be located at a pressure node of the vibrating gas column. This greatly reduces the amount of high frequency energy lost by way of the exhaust pipe. In order further to reduce such losses, a filter 13 may be interposed in the exhaust pipe, which filter is constructed to offer a high impedance to oscillatory energy of the operating frequency while offering only a negligible impedance to the steady flow of the exhaust combustion products. Such a filter is known as a low-pass filter. It may be simply constructed of a pair of branch pipes, each one-quarter wavelength long, and positioned one-quarter wavelength from the opening of the exhaust pipe 12 into the explosion chamber 1. The theory of operation and construction of such acoustic filters is well known and is described, for example, in "Elements of Acoustical Engineering" by H. F. Olson (Van Nostrand, 1940). If desired, the circulating water pipes may likewise be provided with acoustic filters, as indicated. The position of these filters is not critical. They have the same function as the filters in the exhaust pipe and are subject to the same principles of dimensional design, so as to justify the use of the same reference numeral 13 for them, as here indicated. This principle of design would require them to be about five times as long as the filter in the exhaust pipe, hence they are shown broken at a point intermediate their ends.

The forces due to the repeated reflections of the pressure waves of the gaseous medium on the piston-diaphragm 3 are transferred by the turn buckle 15 to the piston-diaphragm 14 which, in turn, transfers them into the liquid medium 18, 21, which may be one-quarter wave long or an odd multiple thereof in the second chamber 16. The assembly consisting of the two diaphragms 3, 14 and the turn buckle 15 thus acts as a piston, driven by the pressures in the explosion chamber 1 and driving the liquid medium in the second chamber 16. The latter, in turn, by reason of its dimensions, acts as a quarter-wave acoustic transformer to transfer the pressure energy of the ex-

plosion chamber 1 to the quarter wavelength crystals 23.

As is well known, optimum energy transfer takes place from one vibrating system to another when their impedances are properly matched. Now the characteristic impedance of the gaseous medium in the explosion chamber 1 is very low, e. g., about 50 mechanical ohms per square centimeter, while the characteristic impedance of the ADP crystal material is very high, e. g., about 600,000 mechanical ohms per square centimeter. Consequently, the design of a transformer to match such widely different impedances presents considerable difficulties. This is especially true when it is desired to restrict the vibratory energy to the form of plane waves and avoid production of wasteful higher modal oscillations, because, as explained above in connection with the dimensions of the explosion chamber, this consideration likewise sets an upper limit of one-half wavelength to the diameter (or shortest side) of the cross-section of the second chamber. In water or oil the speed of propagation of sound is about four times its value in the hot gases of the explosion chamber, i. e., about 4800 feet per second, and the wavelength at a frequency of 5,000 per cycle is about 28 centimeters. Consequently, the shortest side of the cross-section of the second chamber should not exceed 14 centimeters. A factor of safety is advisable so this dimension has been taken as somewhat less than 14 centimeters, e. g., 12 centimeters. Without this restriction it would be possible to match the low impedance of the gas column to the high impedance of the crystals by mere adjustment of the relative cross-sections of the first and second chambers. The theory, construction and mode of operation of acoustic impedance transformers which function by reason of a change in cross-section is well-known in the art and is explained for example, in "Electromechanical Transducers and Wave Filters," by W. P. Mason (Van Nostrand, 1942). However, in order to avoid higher modal oscillations, this cross-section area ratio cannot be increased without limit. In the particular case selected as an example, and assuming circular cross-sections both for the explosion chamber and the transformer chamber, this cross-section area ratio is therefore limited to the figure

$$\left(\frac{12}{4}\right)^2 = 81$$

Applicant's solution of these difficulties comprises a composite transformer whose characteristics are secured in part by adjustment of the dimensions of the transformer chamber 16 as compared with those of the explosion chamber 1, in part by the arrangement of the piezoelectric crystals 23, and in part by the selection of the material of the operating transformer medium. The mechanical impedance looking into the end of quarter wavelength crystals has been determined to be about 0.2 of the characteristic impedance of the crystal material for an ADP crystal. Taking the area of the crystal side of the plate 22 which is filled with crystal ends to be one-half the total plate area, the total impedance worked into is therefore $600,000 \times 0.2 \times 0.5$ or 60,000 mechanical ohms per square centimeter of plate area or a total of

$$60,000 \times \frac{\pi}{4} \times 12^2 = 6.8 \times 10^6 \text{ ohms}$$

The impedance at the piston diaphragm looking into the explosion chamber is

$$50 \times \frac{\pi}{4} \times 4^2 = 628 \text{ mechanical ohms}$$

By reason of the cross-section change associated with the diameter change from 4 centimeters to 12 centimeters alone, the characteristic impedance looking into the liquid medium can be made

$$\left(\frac{12}{4}\right)^2 = 9 \text{ times as great}$$

as the impedance (50 mechanical ohms per square centimeter) of the gaseous medium or 450 mechanical ohms per square centimeter, while the total impedance looking into this medium from the the same point can be made

$$\left(\frac{12}{4}\right)^4 = 81 \text{ times as great}$$

as the 628 ohms impedance of the gas column, i. e., $628 \times 81 = 510,000$ ohms. These figures, however, are insufficient to effect the impedance transformation from 50 ohms per square centimeter at the explosion chamber to 60,000 ohms per square centimeter at the crystal, or from 628 ohms at the explosion chamber to 6.8×10^6 ohms at the crystal-supporting plate. What is required is a medium whose characteristic impedance per square centimeter will be the geometrical mean between the two terminal characteristic impedances; i. e., whose characteristic impedance per square centimeter will be equal to $\sqrt{450 \times 60,000}$ or 5200 mechanical ohms per square centimeter. This impedance is too high for a gas and too low for a liquid. In accordance with the invention, however, it is realized by a combination of a liquid and a gas. The characteristic impedance of water or oil is about 150,000 mechanical ohms per square centimeter and that of air or gas is about 50 mechanical ohms per square centimeter. The desired impedance, 5200 mechanical ohms per square centimeter, is about $1/30$ of the greater of these figures and about 100 times the lesser. It has been found that a proper admixture of two materials of different characteristic impedances partakes of the nature of both components. In particular, if one part by volume of finely divided air bubbles is intermixed with 99 parts by volume of water, the impedance of the mixture will be close to the desired value of 5200 ohms per square centimeter. However, it is impossible to hold the proper amount of air in the form of minute bubbles in suspension in the liquid. Therefore, in accordance with the invention, the proper amount of air by volume is retained in position in the form of minute air bubbles contained in a suitable cellular retainer such as a sheet of sponge rubber 17. Both the material and the volume of the rubber have a negligible effect on the operation, the rubber serving for all practical purposes merely as a matrix in which the air bubbles are embedded.

The air and the sponge rubber in which it is contained are much more compressible than the liquid on either side of it. Therefore, this construction greatly reduces the length of the transformer chamber 16 for a given wavelength. For example, were the transformer chamber wholly filled with water or oil, and one-quarter wavelength long from the piston 14 to the crystal-supporting plate 22 it would measure 7.5 centimeters at an operating frequency of 5,000 cycles per second. With the interposition of the sponge rubber air-supporting sheet 17, however, its length, for the same behavior, is reduced to 1.5 centime-

ters, the sponge rubber sheet being only about 0.25 centimeter in thickness. This reduction in length may be of considerable advantage at lower frequencies where the length of a quarter wave might be awkwardly large. In the present example, however, the length of 7.5 centimeters is not awkwardly large. On the contrary, the length of 1.5 centimeters may under some conditions be awkwardly small. If such should be the case, the transformer chamber may be made an odd multiple of a quarter wave in length, for example, three-quarters of a wavelength, in which case the dimension of 1.5 centimeters becomes 4.5 centimeters. The sponge rubber diaphragm 17 should then preferably be placed at a distance of approximately one-third the length of the transformer chamber measured from the plate 22; i. e., at the pressure node which exists one-quarter wavelength from the high pressure end of the chamber 16. This arrangement has been selected for illustration in the figure. Precise adjustment of the transformer chamber 16 to an odd number of quarter wavelengths is accomplished by movement of the assembly consisting of the crystals 23, the plate 22 and the backing plate 24 toward or away from the explosion chamber 1. This is effected by rotation of the turn buckles 27. Inward movement requires removal of some of the oil and water from the chamber 16 and outward movement requires addition of water and oil. Stop cocks 39, 40 may be provided for this purpose.

The composite impedance transformer of the invention thus permits matching of impedances over a wider range than would be possible at the high frequencies contemplated and without the excitation of higher modal oscillations and consequent energy losses, by adjustment of the cross-section ratio alone.

The quantitative relations employed in the foregoing example may be generalized, for a plurality of fluid media as follows:

Let

p_1 =pressure -----	} In the explosion chamber 1 (ahead of the change in cross-section)
v_1 =particle velocity ----	
A_1 =area -----	
Z_1 =impedance per unit area -----	

p_2 =pressure -----	} In the transformer chamber 16 (following the change in cross-section)
v_2 =particle velocity ----	
A_2 =area -----	
Z_2 =impedance per unit area -----	

Z_3 =impedance of plate 22 and crystals 23
 Z_a =characteristic impedance of first component fluid
 Z_b =characteristic impedance of second component fluid
 Z_c =characteristic impedance of third component fluid
 etc.

V_a =proportional volume of first component fluid
 V_b =proportional volume of second component fluid
 V_c =proportional volume of third component fluid
 etc.
 Z_0 =characteristic impedance of composite fluid medium

Then, ahead of the change in cross-section

$$Z_1 = \frac{p_1}{\xi_1} \quad (1)$$

and following the change,

$$Z_2 = \frac{p_2}{\xi_2} \quad (2)$$

But since volume velocities and pressures are continuous across the cross-section change,

$$p_1 = p_2 \quad (3)$$

$$\xi_1 A_1 = \xi_2 A_2 \quad (4)$$

Dividing (3) by (4) and substituting (1) and (2),

$$\frac{Z_1}{A_1} = \frac{Z_2}{A_2}$$

or

$$Z_2 = \frac{A_2}{A_1} Z_1 \quad (5)$$

This transformation is effected by the cross-section change alone.

The impedance of the explosion chamber 1 regarded as a source is $Z_1 A_1$ and the impedance of the plate 22 and crystals 23 regarded as a receiver is $Z_2 A_2$, there being only one change in cross-section. To match them, a quarter wave transformer is required whose characteristic impedance is the geometrical mean between these two. If this is to be secured with a conduit of area A_2 , this requirement may be expressed as

$$Z_0 A_2 = \sqrt{Z_1 A_1 \times Z_2 A_2} \quad (6)$$

or

$$Z_0 A_2 = \sqrt{Z_1 \left(\frac{A_1}{A_2} \right) A_2 Z_2 A_2}$$

whence

$$Z_0 = \sqrt{Z_1 \left(\frac{A_1}{A_2} \right) Z_2} \quad (7)$$

If there be no change in cross-section, (7) reduces to the more familiar expression

$$Z_0 = \sqrt{Z_1 Z_2} \quad (8)$$

for a quarter wave transmission line.

To obtain a medium having this characteristic impedance Z_0 by combining different fluid media of characteristic impedances Z_a, Z_b, Z_c , etc., and occupying volumes V_a, V_b, V_c , etc., it is only necessary to adjust the proportions in accordance with the formula

$$\frac{V_a Z_a V_b Z_b V_c Z_c \dots}{V_a Z_a + V_b Z_b + V_c Z_c + \dots} = (V_a + V_b + V_c + \dots) Z_0 \quad (9)$$

With only two component media, formula (9) reduces to

$$\frac{V_a Z_a V_b Z_b}{V_a Z_a + V_b Z_b} = (V_a + V_b) Z_0 \quad (10)$$

It will be found by substitution that the figures of the example given above satisfy this formula.

The impedance transformer has been described in connection with its use in applicant's power source, wherein the explosion chamber (source) impedance is low and the crystal (receiver) impedance is high. It is equally applicable to the inverse transformation from a high source impedance to a low receiver impedance.

It is recommended that the apparatus be operated at a fairly high energy level. For example, if the oscillating pressure within the explosion chamber 1 has an amplitude of one atmosphere, the total pressure then varies between

zero and two atmospheres. When this high value of alternating pressure is maintained the energy density will be given by the formula:

$$\text{Energy density} = \frac{1}{2} \frac{Pm^2}{\rho v} \times 10^{-7} = 1000 \text{ watts per square centimeter}$$

where

10 Pm = peak value of alternating pressure (one atmosphere)

ρ = density of gaseous medium

v = velocity of sound in the gaseous medium

Not all of this energy is transmitted to the transformer chamber 16, since if it were so transmitted, standing pressure waves could not be maintained in the explosion chamber 1. However, when one-quarter of the stored energy is transferred in each operating cycle, one-quarter of the above factor or 250 watts per square centimeter becomes available for transfer. With an explosion chamber of the dimensions shown and discussed above, this energy density results in a transfer of about three kilowatts. Since the overall length of the entire system is not more than about two feet and its overall diameter not more than about six inches, an exceedingly compact unit, capable of delivering close to three kilowatts of electric power, is thus made available.

Operation at high energy levels offers the further advantage that the fuel pump 8, which injects the atomized fuel at the low pressure instants of the combustion cycle, need work only against very low pressures and therefore need require only a small amount of power.

What is claimed is:

1. A source of oscillatory energy which comprises a substantially closed acoustic resonant chamber, thermal means for setting up standing pressure waves of a gas within said chamber at an orderly high frequency and a pressure-responsive piezoelectric element coupled to said chamber in such fashion as to be actuated by the pressures of said waves.

2. A source of oscillatory energy which comprises a pressure-supporting vessel, an elastic fluid within said vessel, an elastic member coupled to said fluid, thermal means for producing pressure changes of said fluid in ordered time sequence, and means for deriving oscillatory electric energy from strains in said elastic member.

3. A source of oscillatory energy which comprises a pressure-supporting vessel, an elastic fluid within said vessel, an elastic member coupled to said fluid, means for producing pressure changes of said fluid in ordered time sequence, means for deriving electric energy from strains in said elastic member, and means for feeding back a portion of said electric energy to control said time sequence.

4. A source of oscillatory energy which comprises a pressure-supporting vessel, an elastic fluid within said vessel, an impedance transformer coupled to said fluid, an elastic member coupled to said impedance transformer, thermal means for producing pressure changes of said fluid in ordered time sequence, and means for deriving oscillatory electric energy from strains in said elastic member.

5. A source of oscillatory energy which comprises a closed vessel, a wave-supporting fluid within said vessel, a mechanical-electrical transducer coupled to said fluid, said transducer be-

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ing adapted to deliver electric energy in response to mechanical pressures thereon, and means for developing standing waves of compression in said fluid of a wavelength such that said transducer is coupled to a high pressure region of said fluid.

6. A source of oscillatory energy which comprises a closed vessel, a fluid within said vessel capable of supporting standing waves of a natural frequency and wavelength determined by the nature of the fluid and the dimensions of the vessel, means for developing standing waves in said fluid, and a mechanical-electrical transducer element coupled to said fluid, said element having a natural oscillation frequency substantially like the natural frequency of said standing waves.

7. A source of oscillatory energy which comprises a closed vessel, a fluid within said vessel capable of supporting standing waves of a natural frequency and wavelength determined by the nature of the fluid and the dimensions of the vessel, means for developing standing waves in said fluid, a mechanical-electrical transducer element coupled to said fluid, said element having a natural oscillation frequency substantially like the natural frequency of said standing waves, a load circuit, and electric connections from said transducer element to said load circuit.

8. A source of oscillatory energy which comprises a closed vessel, a fluid within said vessel capable of supporting standing waves of a natural frequency and wavelength determined by the nature of the fluid and the dimensions of the vessel, means for developing standing waves in said fluid, a mechanical-electrical transducer element coupled to said fluid, said element having a natural oscillation frequency substantially like the natural frequency of said standing waves, a load circuit, means for supplying electric energy derived from said transducer element to said load circuit, and means for feeding back a portion of said electric energy to maintain said standing waves.

9. A source of oscillatory energy which comprises a pressure-supporting vessel, a fluid within said vessel capable of supporting standing waves of a natural frequency and wavelength determined by the nature of the fluid and the dimensions of the vessel, means for developing standing waves in said fluid, said vessel having a length substantially equal to an integral number of half wavelengths of sound in said fluid and having a cross-section whose shortest dimension is less than said half wavelength, a movable piston for adjusting the length of said vessel and for responding to the changing pressures in said vessel, a vibratory mechanical-electrical transducer whose natural frequency accords with the frequency of said standing waves and impedance transformer means for transferring the energy of pressures exerted upon said piston to said mechanical-electrical transducer.

10. A source of oscillatory energy which comprises a pressure-supporting vessel, a fluid within said vessel capable of supporting standing waves of a natural frequency and wavelength determined by the nature of the fluid and the dimensions of the vessel, means for developing standing waves in said fluid, said vessel having a length substantially equal to an integral number of half wavelengths of sound in said fluid, and having a cross-section whose shortest dimension is less than said half wavelength, a movable piston for adjusting the length of said vessel and

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for responding to the changes in pressure in said vessel, a vibratory mechanical-electrical transducer whose natural frequency accords with the frequency of said standing waves, impedance transformer means for transferring the energy of pressures exerted upon said piston to said mechanical-electrical transducer, and means for feeding back electrical energy developed by said transducer to control the operation of said standing wave developing means whereby to control the frequency of said waves.

11. A source of oscillatory energy which comprises a pressure-supporting vessel, a fluid within said vessel capable of supporting standing waves of a natural frequency and wavelength determined by the nature of the fluid and the dimensions of the vessel, means for developing standing waves in said fluid, said vessel having a length substantially equal to an integral number of half wavelengths of sound in said fluid and having a cross-section whose shortest dimension is less than said half wavelength, a movable piston for adjusting the length of said vessel and for responding to the changes in pressure in said vessel, a vibratory mechanical-electric transducer whose natural frequency accords with the frequency of said standing waves, impedance transformer means for transferring the energy of pressures exerted upon said piston to said mechanical-electrical transducer, an exhaust pipe connecting with said vessel, and an acoustic filter connected to said exhaust pipe, adapted to block high frequency pressure energy while permitting release of pressures not directly associated with said standing waves.

12. A source of oscillatory energy which comprises a pressure-supporting vessel, an elastic fluid within said vessel, means for setting up standing pressure waves of said fluid within said vessel, a mechanical-electrical transducer element of high input impedance, and means for transforming the standing wave pressure energy of said chamber to match said high input impedance which comprises a second chamber containing a liquid and a layer of trapped bubbles of gas.

13. A source of oscillatory energy which comprises a pressure-supporting vessel, a gaseous medium of low impedance within said vessel, means for setting up standing pressure waves of said medium within said vessel, a mechanical-electrical transducer element of high input impedance, and means for transforming the standing wave pressure energy of said chamber to match said high input impedance which comprises a second chamber containing a liquid and a layer of a material comprising a multitude of separate cells, each cell containing a gas.

14. A source of oscillatory energy which comprises a pressure-supporting vessel, an elastic fluid within said vessel, means for setting up standing pressure waves of said fluid within said vessel, a mechanical-electrical transducer element of high input impedance, and means for transforming the standing wave pressure energy of said chamber to match said high input impedance which comprises a layer of a soft, solid material comprising a multitude of separate cells, each cell containing a gas.

15. In a system for developing electrical energy from mechanical energy, and in combination with a low characteristic impedance source of oscillatory pressures and a high impedance mechanical-electrical transducer adapted to deliver oscillatory electric current when actuated by

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oscillatory pressures, an impedance-matching transformer which comprises a chamber coupled to said source and to said transducer, a liquid mass in said chamber, and a plurality of minute gas bubbles suspended in said liquid.

16. In a system for developing electrical energy from mechanical energy, and in combination with a low characteristic impedance source of oscillatory pressures and a high impedance mechanical-electrical transducer adapted to deliver oscillatory electric current when actuated by oscillatory pressures, an impedance-matching transformer which comprises a chamber coupled to said source and to said transducer, a liquid mass in said chamber, and a sheet of soft, liquid-tight cellular material suspended in said liquid, the cells of said material containing gas.

17. A confined column of gas, a mechanical-electrical transducer, a liquid acting as a coupling medium between said gas column and said transducer, means for developing standing waves in said gas column whereby corresponding pressure impulses are transmitted through said coupling medium to actuate said transducer and therefore to develop electrical energy, means for feeding back a portion of said electrical energy

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to maintain said standing waves, said transducer, coupling medium, and gas column being tuned to the same natural frequency of vibration.

WARREN P. MASON.

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