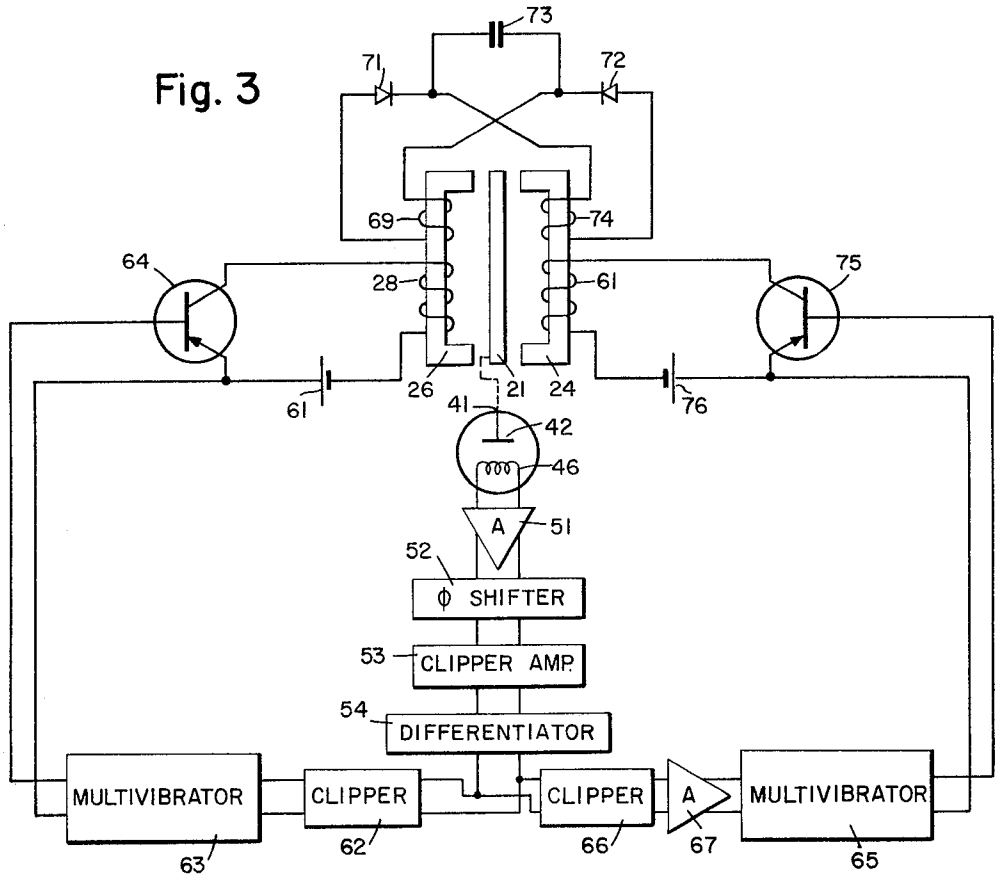
Sept. 20, 1966 B. L. SNAVELY 3,274,538

ELECTROACOUSTIC TRANSDUCER

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Fig. 3



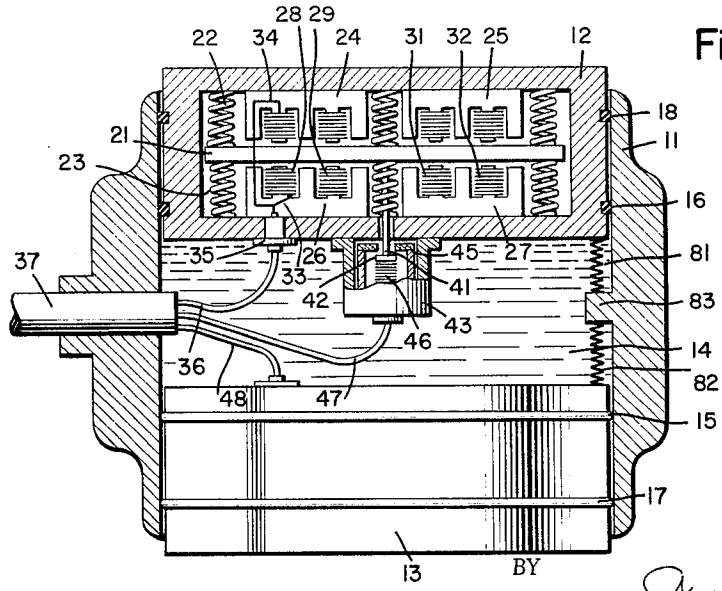


Fig. 1

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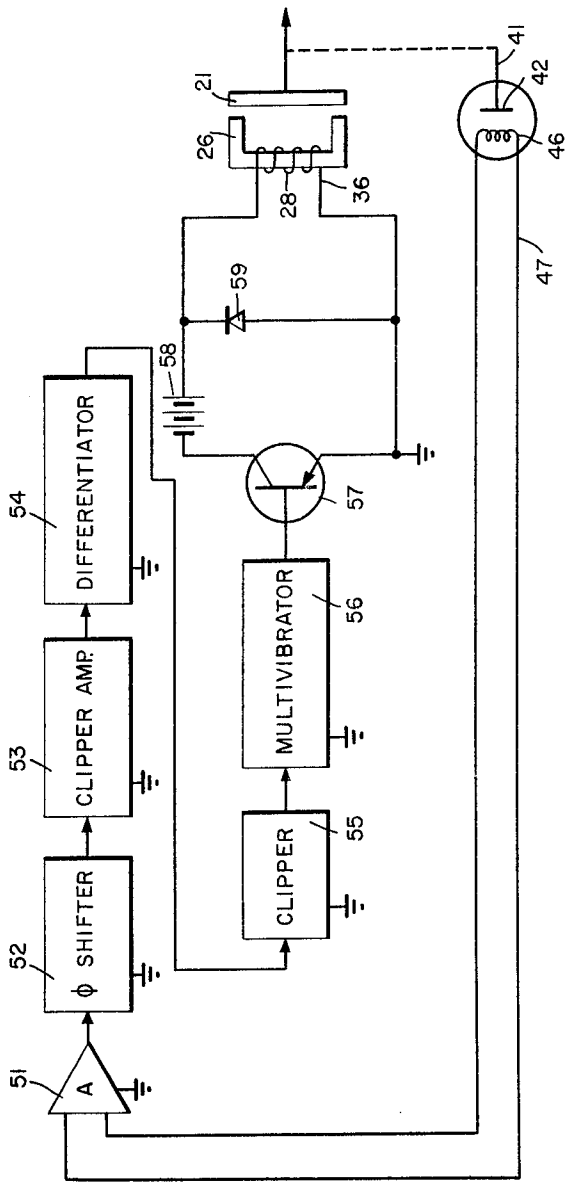
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ELECTROACOUSTIC TRANSDUCER

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Fig. 2



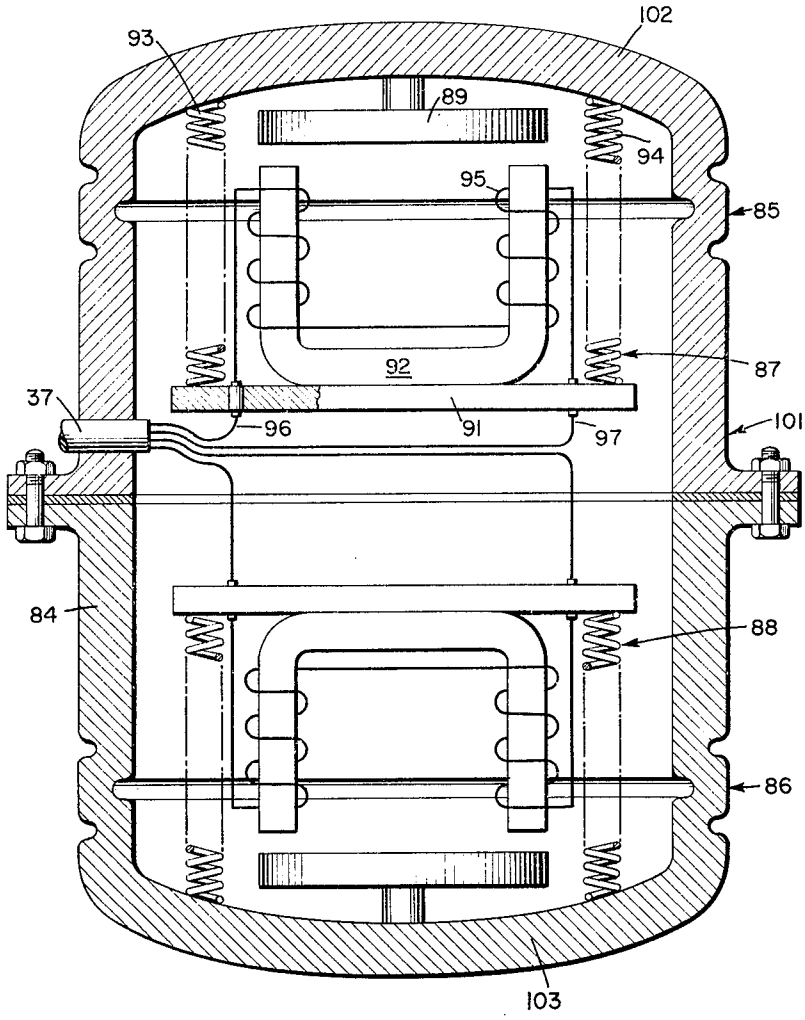
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Fig. 4



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United States Patent Office 3,274,538 Patented Sept. 20, 1966

3,274,538

ELECTROACOUSTIC TRANSDUCER

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Original application Sept. 19, 1960, Ser. No. 57,085, now Patent No. 3,219,969, dated Nov. 23, 1965. Divided and this application Oct. 30, 1963, Ser. No. 326,652

4 Claims. (Cl. 340—8)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This application is a division of my copending application, Serial No. 57,085, now Patent No. 3,219,969, filed Sept. 19, 1960.

This invention relates to acoustic transducers and more particularly to electroacoustic transducers that are to be used for underwater purposes.

This invention also relates to control systems for such transducers and more particularly to a control system for insuring substantially constant frequency operation of electroacoustic transducers.

In previous transducers special means are used for acoustically insulating the several parts of the transducer from the structure on which the transducer is supported. Unless these insulating means are used, the supporting structure absorbs some of the acoustic energy from the transducer and either converts this energy into heat or radiates it as acoustic energy. In the latter case, the energy radiated from the structure nearly always effects the directional radiation pattern adversely. In the former case, the efficiency of conversion of electrical to mechanical energy is reduced.

For transducers operating at fairly great depths in the water, i.e. between 20 and 2,000 fathoms, the reduced efficiency of the transducer will have damaging effects on operation. At these depths it is essential that maximum efficiency of electric to acoustic energy be obtained in order to generate high volume signals into the surrounding water medium.

Accordingly, it is an object of this invention to provide a new and improved electroacoustic transducer capable of operating under the surface of the water at high efficiencies and for emitting large amounts of power into the surrounding sea particularly at great depths.

It is another object of this invention to provide a new and improved electromechanical transducer that is highly efficient.

It is a further object of this invention to provide a new and improved circuit that requires small amounts of power for controlling the movement of an oscillating armature.

It is still another object of this invention to provide a new and improved circuit for effecting maximum energy transfer between a pair of electromagnetic members.

A further object of this invention is to provide a new and improved underwater electroacoustic transducer and transducer control system that is very reliable; will operate at great depths in the water; that will emit high power, frequency stabilized signals into the ocean at maximum efficiency; and which is relatively inexpensive.

Various other objects and advantages will appear from the following description of several embodiments of this invention, and the novel features will be particularly pointed out hereinafter in connection with the appended claims.

The manner in which this invention achieves these objects can best be understood by reference to the accompanying drawings in which:

FIG. 1 is a sectional view of a preferred embodiment of the actual transducer apparatus;

FIG. 2 is a schematic illustration of one form of a transducer control apparatus;

FIG. 3 is a schematic diagram of another embodiment of a transducer control apparatus; and

FIG. 4 is a sectional view of another embodiment of the transducer.

Of course it is to be understood that like reference numerals will be used throughout the several drawings to designate like or similar parts.

Referring now to FIG. 1 of the drawings, a sectional view of the electroacoustic transducer is shown, which comprises a rigid, hollow, cylindrical container **11** having a pair of oppositely positioned open ends. A pair of movable elements such as the pistons **12** and **13** illustrated, are each located at a respective end of the cylindrical container **11** and are slideable in proximity to the interior wall of the container. A compressible spring-like medium **14**, preferably consisting essentially of liquid silicone is filled within the volume of cylinder **11** between pistons **12** and **13**. The fluid spring **14** is retained within the cylindrical container by means of the O ring **15** contained on piston **13** and the O ring **16** contained on piston **12**.

O rings **17** and **18** mounted on pistons **13** and **12**, respectively, contact the interior walls of cylindrical member **11** and prevent sea water from intermixing with the silicone liquid **14** which is used as a spring-like member. It is essential that the spring-like medium be of sufficient stiffness to balance hydrostatic pressures which are exerted against the pistons **12** and **13** when the device is lowered to great depths in the ocean. It is also necessary that the liquid spring be of sufficient compliance or softness so as to permit it to be compressed when the pistons are actuated by forces associated with acoustic radiation thereof, i.e. when the electromotive means contained within each piston synchronously and reciprocally translates the pistons in opposite directions with respect to each other.

The pistons **12** and **13** are maintained within case **11** in such a manner as to prevent them from falling out of the case by springs **81** and **82** to which they are respectively secured by any suitable means. Springs **81** and **82** are also secured to block **83** which is formed on the interior wall of case **11**.

Each of the substantially cylindrical pistons **12** and **13** contains its own electromotive apparatus. A sectional view of the electromotive apparatus associated with piston **12** has been disclosed, the moving means of piston **13** being essentially the same as that of piston **12**; therefore it is not believed necessary to specifically disclose the construction of the means to move piston **13** up and down. Armature **21** is centrally located within the hollow portion of piston **12** and is supported by springs, such as **22** and **23**, which contact the interior face of the piston and one side of the armature. Cores **24** and **25** mounted on the upper face of piston **12**, and cores **26** and **27** mounted on the lower face of the piston have a plurality of coils wound thereon which serve as the electromotive means for driving armature **21**. Coils **28** and **29**, wound on core **26**, are series connected to each other and to the coils **31** and **32**, wound on core **27**; the series circuit formed by these coils being connected to lead **33**. The coils wound on cores **24** and **25** are series connected to each other and are connected to lead **34**. Leads **33** and **34** are maintained in place by housing **35**, which is located on the lower face of piston **12**. A return lead (not shown) is connected from the other end of each of these series circuits back to housing **35**. A small cable **36** carrying leads **33** and **34** and the return leads associated

therewith is connected between housing 35 and the larger cable 37.

Shaft 41, mounted on armature 21, contains a soft iron disc 42 mounted at the end thereof. Disc 42 is contained within housing 43 which contains a bar-like structure 45 and a coil 46. Both ends of coil 46 are coupled to the large cable 37 by means of a pair of leads contained in cable 47. Bar-like structure 45 comprises a pair of soft iron members disposed on the upper and lower portions thereof and a pair of permanent magnets forming the vertical walls thereof. A soft iron core (not shown) is disposed within coil 46, thus establishing a magnetic circuit through the coil. Of course, it is to be understood that any other conventional position indicating means may be employed.

The amplitude of the signal appearing across the leads in cable 47 is indicative of the instantaneous velocity of armature 21 with respect to piston 12. As the armature 21 and the shaft 41 carried thereby are moved up and down, the motion of the disc 42 relative to member 45 causes a change in the magnetic flux, from the permanent magnets in structure 45, passing through the soft iron core disposed within coil 46. This changing flux generates a voltage within coil 46.

The operation of the electroacoustic transducer illustrated in FIG. 1 will now be described in detail. Once in every interval of time a current pulse is supplied to coils 28, 29, 31 and 32 by way of lead 33. This current produces a flux in the cores 26 and 27 which is coupled to armature 21 composed of ferromagnetic material thereby imparting electromagnetic forces to the armature causing it to be attracted towards the core. Movement of armature 21 towards cores 26 and 27 in response to the current pulse causes the springs 23 mounted on the lower interior face of piston 12 to be compressed while the springs 22 mounted on the upper interior face of the piston will expand. When the pulse is removed from the windings 28, 29, 31 and 32, springs 23 will expand and springs 22 will compress causing armature 21 to oscillate from a position in proximity to cores 26 and 27 to a position in proximity in cores 24 and 25. When the armature 21 is in proximity to cores 24 and 25, springs 22 will again expand causing the armature to be returned towards cores 26 and 27. As the armature 21 moves toward cores 26 and 27 and away from cores 24 and 25, another current pulse is supplied to the coils wound on the cores 26 and 27.

As the armature 21 oscillates back and fourth between cores 24 and 25 and cores 26 and 27, the disc 41 oscillates within housing 43 producing an alternating voltage on lead 47 indicative of the armature position. In order to insure equal variations with respect to the upper and lower faces of armature 21, a pulse is supplied to the coils wound on cores 24 and 25 by way of lead 34 180° out of phase with the pulse supplied to the lead 33. Application of two pulses per cycle increases the power output to the electromotive apparatus but satisfactory operation can be achived by applying pulses only to the coils on cores 26 and 27. Control pulses are supplied to piston 13 by way of lead 48 which is coupled to cable 37 in such a manner as to insure synchronous operation of pistons 12 and 13. These pulses occur in such a manner as to simultaneously insure inward movement of the pistons 12 and 13, i.e. towards the center of the cylinder, and to simultaneously insure outward movement of these pistons, so as to effect volume displacements in opposite directions from each of the radiating pistons.

This type of operation causes any forces which may be produced by pistons 12 and 13 on the cylindrical container 11 to be cancelled.

In this manner, maximum efficiency is obtained with the electroacoustic transducer because no net forces are applied to the hollow container in which the moving pistons are contained.

Referring now to FIG. 2 of the drawings illustrating one embodiment of the control element for the armature 21 of FIG. 1, which comprises the position indicating mechanism of a control circuit for applying current pulses to the coils of the electromotive element in the core 26 of one of these elements. It is to be understood that this is a schematic representation and that the electromotive means comprises a pair of cores and the associated coils. In this embodiment, only one pulse is applied to the electromotive structure during each cycle and accordingly either the cores 26 and 27 mounted on the lower face of the piston 12 may be removed or those cores mounted on the upper face and their associated circuitry may be removed, i.e. it is only necessary to include a single electromagnetic circuit for moving armature 21.

When the armature 21 oscillates back and forth with respect to core 26, an alternating voltage, the amplitude of which is indicative of the instantaneous position of armature 21, is generated in coil 46 due to the movement of member 42 coupled to the armature by way of shaft 41. The alternating voltage generated in coil 46 is coupled to a conventional A.C. amplifier 51 by way of leads 47. The amplified position signal obtained from amplifier 51 is coupled to phase shifter 52, the output of which is fed to a conventional clipper amplifier 53. The output voltage of the clipper amplifier 53, a square wave of the same frequency and phase as the output of phase shifter 52, is fed to a conventional differentiator circuit 54 that supplies a positive and negative spike once for each cycle of oscillation of armature 21. The differentiator circuit 54 is coupled to conventional clipper circuit 55 that removes one of the spikes generated by differentiator 54, thus feeding one spike per cycle of armature 21 movement into a conventional multivibrator circuit 56. Multivibrator 56 is of the type that normally produces one pulse in any predetermined period of time, the predetermined period of time being slightly greater than the frequency with which armature 21 is expected to oscillate. When a spike is supplied to multivibrator 56 from clipper circuit 55, it changes state producing an output pulse of predetermined width which is supplied from the multivibrator to the base of transistor 57.

Transistor 57 is normally maintained beyond cutoff, i.e. in a non-conducting state, because of the positive voltage applied to the base thereof from multivibrator 56. When the multivibrator produces a negative impulse of predetermined width, transistor 57 is suddenly rendered conductive and a current path is established from battery 58 through coil 28, lead 36 and the emitter and collector of transistor 57. The current through coil 28 changes the flux of core 26 thereby causing an electromagnetic force to be exerted on armature 21 by core 26. Thus, periodic movement of armature 21 is insured by the mechanical forces imparted thereto by the springs 22 and 23 and the electromotive forces applied thereto by means of the winding 28 and core 26.

In order to effectively reduce the flux level in core 26, rectifier 59 is connected in parallel with the winding 28. This causes the current which is flowing in coil 28 to flow through the rectifier when the transistor 57 is again placed in the non-conducting region in response to the termination of the predetermined width pulse produced by multivibrator 56. The diode 59 also insures complete cutoff of transistor 57 when the pulse supplied thereto from multivibrator 56 is terminated. It should thus be apparent that transistor 57 and the circuitry associated therewith is a means for providing current impulses to the electromotive apparatus comprising core 26, coil 28 and armature 21 only during a portion of each cycle of the alternating signal generated across winding 46 by the movement of armature 21. Phase shifter circuit 52 shifts the phase of the signal supplied to differentiator 54 so that the impulse provided by multivibrator 56 to transistor 57 occurs at the correct time to move armature 21 with respect to core 26.

Referring now to FIG. 3 of the drawings, there is disclosed another embodiment of the control element for imparting synchronized motion to armature **21**, comprising an electromotive apparatus utilizing both cores **24** and **26**. Apparatus for generating a signal indicative of the instantaneous position of armature **21** of FIG. 3 is substantially the same as that disclosed for the similar apparatus of FIG. 2. A positive and a negative spike are obtained from differentiator **54** once each cycle, the spikes being 180° out of phase. One of the pulses, for example the negative pulse, is coupled from the differentiator **54** to the multivibrator **63** by way of clipper **62**, the clipper **62** eliminating the other spike, in this case the positive spike. The negative spike voltage applied to multivibrator **63** causes the multivibrator to change state and provide a negative pulse to base of transistor **64** thereby suddenly rendering this transistor into the conducting state. The transistor **64** is normally maintained beyond cutoff because of the positive voltage supplied thereto by multivibrator **63** prior to the time a negative pulse is fed thereto from clipper **62**.

The output of differentiator circuit **54** is also coupled to multivibrator **65** by way of clipper circuit **66** and phase inverting amplifier **67**. The clipper circuit **66** removes the negative spike produced by differentiator **54** and feeds the positive spike to phase inverting circuit **67** so that a negative pulse is supplied to the input of multivibrator **65** once each cycle and 180° out of phase with the negative spike supplied to multivibrator **63**. The negative pulse fed into multivibrator **65** causes a negative pulse of predetermined width to be coupled to the base of transistor **64** thereby rendering that transistor in a conducting state while multivibrator **65** is producing the negative pulse.

Multivibrators **63** and **65** are of the type having a certain natural period of oscillation which is slightly greater than the period of oscillation of armature **21** under normal operating conditions. This is to insure oscillation of the armature **21** if it is in a non-oscillating or steady position. Once the armature **21** is started into oscillation it will be maintained in such a state by the control circuit.

When the negative impulse is supplied to the PNP transistor **64** from the multivibrator **63**, the transistor is suddenly rendered in a conducting state and current flows from battery or power supply **68** through the emitter and collector of transistor **64** and the coil **28** wound on core **26**. When the current impulse from battery **68** is coupled through transistor **64** to winding **28**, the flux on core **26** is driven in one direction, for example a positive direction, inducing a voltage in the secondary winding **69** of core **26**. The voltage induced in winding **69** in response to the positive flux change of core **26** will have no effect on the flux level of core **24**. This is because rectifiers **71** and **72** serve to block any current that would normally flow from coil **69** to **74** as a result of the negative voltage fed to the anode of diode **71** in response to the positive flux change in core **26**.

When the transistor switch is rendered non-conducting in response to the positive output voltage of multivibrator **63**, which occurs when the predetermined width pulse terminates, the flux in core **26** changes in a direction opposite to that which occurs when a current pulse is applied through winding **28**, i.e. a negative flux change. When the flux level in core **26** is changing in the negative direction, a voltage is induced in winding **69** causing a positive voltage to be produced at the anode of diode **71**. This positive voltage causes a current flow through capacitor **73** and back to the other terminal of secondary winding **69** when the flux rate of change is initially changed because the condenser **73** appears substantially as a short circuit to an initially changing volage. As current continues to flow through the diode **71**, a charge is built up on capacitor **73** raising the impedance thereof and current then flows from one end of secondary winding **69** through diode **71**, coil **74** wound on core **24**, and diode **72** back to the other end of coil **69**. This effects an energy transfer from core **26** to core **24** after transistor **64** has been again rendered in the non-conducting state. This arrangement permits most of the magnetic energy which is contained in core **26** when current flow through transistor **64** is terminated to be transferred to core **24**, thus removing almost all of the residual magnetic field existing in core **26**.

The negative output impulse from multivibrator **65** is coupled to the base of normally non-conducting transistor **75** at a different time than the time that the negative impulse is supplied to transistor **64**. Thus current is supplied to winding **61** at a different time than it is supplied to winding **28** and these times are 180° out of phase with respect to movement of armature **21**. When current is supplied to coil **61** from battery **76** through transistor **75**, the change in flux of core **24** exerts sufficient force on armature **21** so as to attract the armature in the same manner that it is attracted by the flux change of core **26**. When transistor **75** is again placed in the cutoff region, a similar change of energy between core **24** and **26** occurs as when transistor **64** is rendered in the cutoff position. Thus, the positive voltage appearing at the anode of diode **72** when the flux level in core **24** is changing after transistor **75** has cut off will remove the charge which was built up across condenser **73** due to the previous half cycle current conduction through coil **69**, diode **71** and condenser **73**. Current from coil **74** and diode **72** through condenser **73** and back to the other terminal of coil **74** will tend to charge condenser **73** in the opposite direction to which it has previously been charged. When the charge across condenser **73** has again been built up sufficiently, current will flow through diode **72**, coil **69**, diode **71** and back again to coil **74**.

In this manner a complete energy transfer between the cores **24** and **26** is effected by applying pulses to transistors **64** and **75** at different times in alternate succession. This results in maximum efficiency energy transfer between the two cores, reducing the residual magnetism of each to the flux value which it had under initial operating conditions.

Referring now more particularly to FIG. 4 of the drawings, which illustrates a cross-sectional view of another embodiment of the invention comprising transducer **101**. The transducer case is a closed, hollow shell, preferably of circular cross-section composed of cup-shaped portions secured together, each of said cup-shaped portions having a partially curved bottom surface or diaphragms **102** and **103**, respectively and a side wall **84** having pleated portions **85** and **86**. The entire shell is preferably made out of steel that is thick enough to be of sufficient stiffness to balance expected hydrostatic pressures exerted thereon when it is in use.

The elements or diaphragms **102** and **103** are concave with respect to the interior of the transducer in order to increase the strength of the shell, particularly at the corners. Pleated sections **85** and **86** each comprise a plurality of alternately arranged exterior and interior indentations in the wall **84**. Only two exterior and one interior indentations being shown for purposes of illustration; the interior indentation being between the exterior ones. These sections are designed to compress against each other when diaphragms **102** and **103** are drawn towards each other and to expand when the diaphragms are both expanding into the surrounding medium.

Apparatus for synchronously moving elements **102** and **103** in opposite directions at the same time is employed. This actuating means is quite similar to the electromotive inertia system employed in the transducer of FIG. 1 Motivating means **87** is coupled to movable portion **102** of shell **84** while motivating means **88** is coupled to movable portion **103**. Since the motivating elements are identical, it is deemed necessary to describe only one of them.

Armature **89** made of a ferromagnetic material similar to armature **21** of FIG. 1 is secured to the interior face of element **102**. Plate **91** having a soft iron core **92** mounted thereon is coupled to the same face of shell **84** as is armature **89** by springs **93** and **94**, fixed thereto, thus forming an inertial system. Coil **95** is connected to leads **96** and **97** forming part of cable **37** and which supply control signals to the motivating means.

The operation of this embodiment will now be described in detail. Control pulses are simultaneously applied to motivating elements **87** and **88**, causing movable elements **102** and **103** to be drawn towards the center portion of the shell. The shell must be of sufficient compliance or softness to cause the indentations of pleated sections **85** and **86** to compress together when electromagnetic energy is applied to the armature. Thus, the wall **84** of the transducer may be considered as a spring-like, compliant medium.

After the pulse has terminated, springs **92** and **93** push the interior wall of element **102** away from platform **91**. At the same time, similar forces in an opposite direction are exerted by the inertial system associated with motivating element **88** against the interior wall of element **103**. In this manner, the indented portions of pleated sections **85** and **86** expand and both surfaces **102** and **103** are forced apart causing expansion of the surrounding medium. Elements **102** and **103** are again drawn together when the next periodic pulse is applied to the electromotive apparatus. In this manner elements **102** and **103** are synchronously moved in opposite directions causing acoustic or pressure energy to be radiated into the medium surrounding transducer **101**. The frequency of the generated energy depends on the period of the input pulses supplied to the motivating system which is in turn dependent on the natural frequency of the inertial system.

Periodic input pulses may be applied to the apparatus of FIG. 1 or FIG. 4 from a fixed frequency source, or a feedback arrangement such as disclosed in FIG. 2 may be utilized for transducer **101** of FIG. 4. Of course it is to be understood that any suitable position pickup may be utilized with the system of FIG. 4 if a feedback arrangement is employed.

The transducers of FIGS. 1 and 4 employ spring mass inertial driving systems rather than a fixed motivating means because in the latter type device the air gap between the electromagnetically actuated core and armature is varied as the transducer depth in the water changes. Thus, the air gap would have an optimum value for conversion of electrical to mechanical energy only over a limited range of water depth. In order to obtain efficient transducer operation for great variations in water depth and pressure, it is essential that the overall gap between the core and armature remain fixed as these exterior conditions are altered. Such as independence of hydrostatic water pressure is secured by the employed intertial driving unit.

It should now be apparent that there has been herein disclosed an electroacoustic underwater transducer that transfers electric energy to mechanical energy with a high degree of efficiency. This transducer is capable of emitting high amounts of power to the adjacent underwater medium in which it is located at great depths with great reliability.

It will be understood that various changes in the details, materials and arrangements of parts, which have herein been described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.

What is claimed is:

1. An underwater acoustic transducer comprising,

hollow cup-shaped elements secured together to form a closed compliant shell, each cup-shaped element having a bottom and side surface,

motivating means in each of said cup-shaped elements coupled to said bottom surfaces for movement thereof, said side surfaces being of sufficient softness to compress when the bottom surfaces are actuated by said motivating means.

2. An underwater acoustic transducer as defined in claim **1**, wherein the motivating means is synchronously operated for moving said bottom surfaces in opposite directions.

3. An underwater acoustic transducer as defined in claim **1**, wherein each of said motivating means is comprised of an armature secured to the bottom surface and a coil mounted within said cup-shaped element, whereby said armature and said bottom surface are drawn toward said coil upon application of an electrical signal to said coil.

4. An underwater acoustic transducer as recited in claim **1**, wherein said side surfaces contain a plurality of pleated sections to enable easy compression thereof.

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