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HYDRAULIC ENERGY STORAGE SYSTEM

Filed July 31, 1962

2 Sheets-Sheet 1

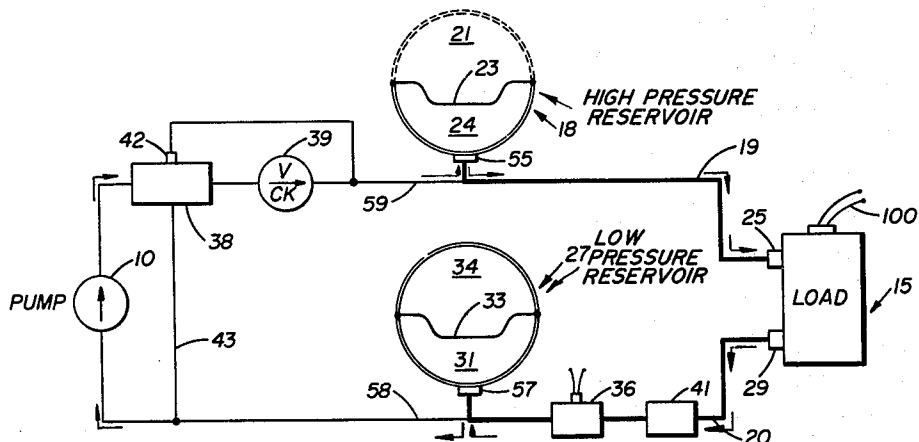


Fig. 1

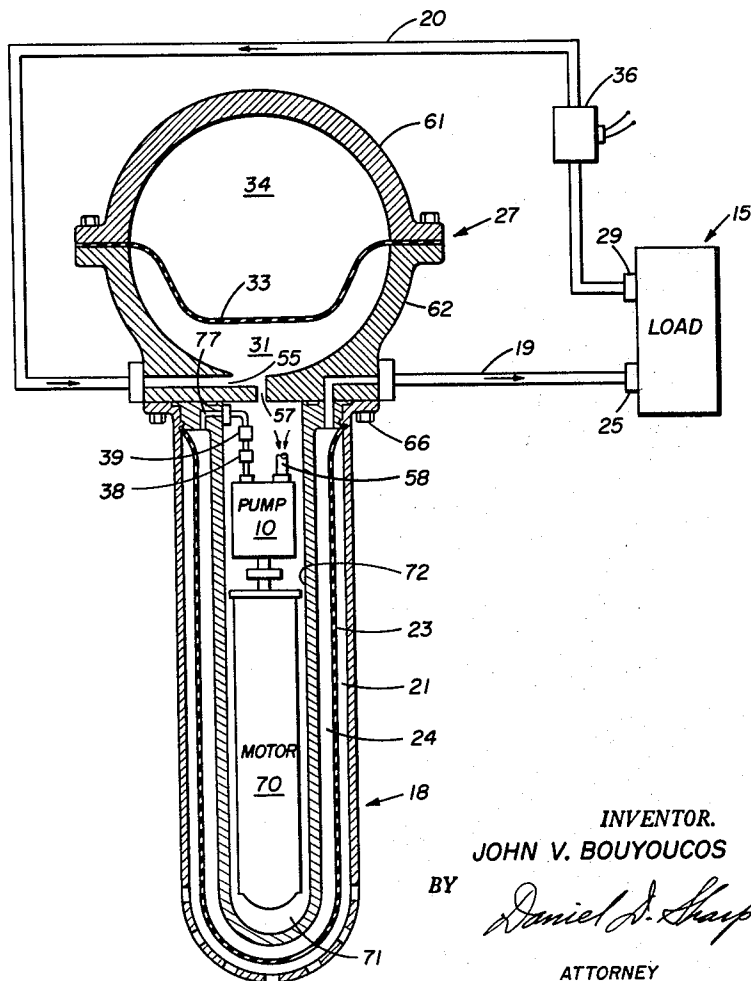


Fig. 2

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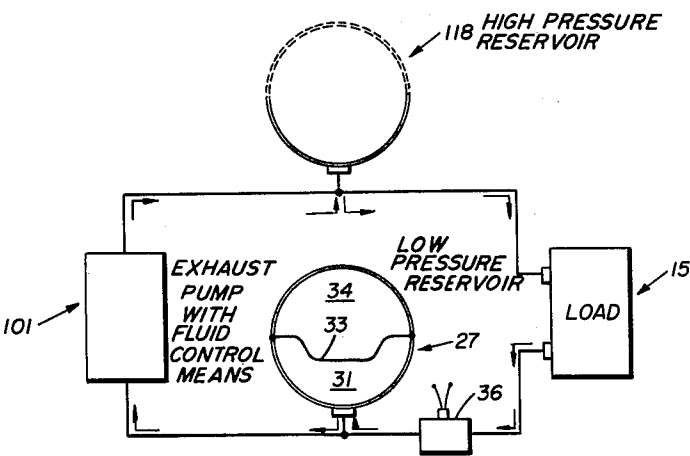


Fig. 3

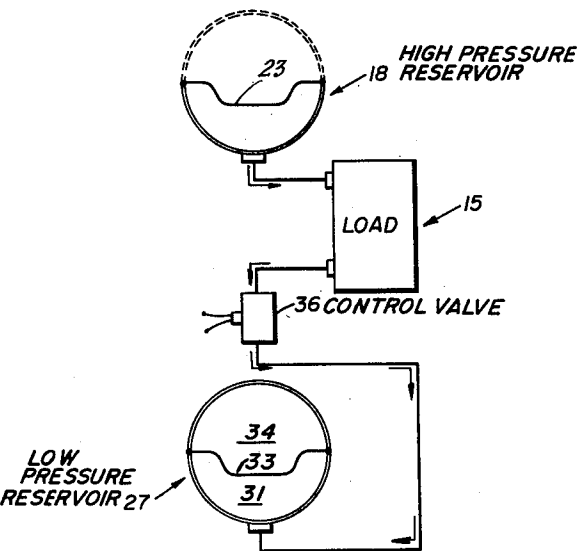


Fig. 4

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HYDRAULIC ENERGY STORAGE SYSTEM

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This invention relates to a hydraulic energy storage power supply which uses the sea pressure head at moderate to great submergence depths as a reservoir of high pressure or potential energy. In combination with a further reservoir maintained or initially set at a pressure that is low relative to sea pressure head, large energy delivery rates may be achieved and sustained over substantial periods of time. The system of the invention enables significantly greater quantities of total energy to be put to work than is practical with conventional hydraulic energy storage systems. The invention has particular applicability as a power supply for deep-planted hydroacoustic transducers as described in copending application for U.S. Letters Patent Serial No. 151,516, filed November 10, 1961, and is equally well suited for deep submergence emergency propulsion systems and for other undersea devices which demand high energy rates for reasonable time periods.

Conventional hydraulic energy storage systems are known which are based on the potential energy of a gas under compression. Such systems may be used, for example, to supply peak power demands in hydraulic systems wherein the average power requirements are relatively low. These systems commonly use an accumulator which is simply a pressure vessel into which oil or some other hydraulic fluid can be pumped against a compliant gas, usually separated from the hydraulic fluid by either a piston or flexible barrier. During a typical operating cycle, the accumulator is charged by introducing hydraulic fluid into the accumulator at low energy rate by means of a hydraulic pump. This operation gradually decreases the volume within the accumulator occupied by the gas and increases the gas pressure exerted on the fluid in the accumulator. A pressure difference is thus established between the high pressure at the accumulator and the low pressure reservoir of the system. Later in the cycle, the fluid may be extracted from the high pressure accumulator at high energy rate (high flow rate) over a relatively short period of time; the fluid so removed passes through the load device, such as an acoustic energy generator, to accomplish useful work.

Since gas-loaded accumulators depend upon the compression of gas for stored energy, their performance obeys the well-known gas law. During expansion or compression, the gas law states that

$$PV^n = \text{constant}$$

where P is the pressure of the gas, V its volume, and n is a coefficient whose value lies between 1 and 1.4 depending on whether the volume change occurs under predominantly isothermal or predominantly adiabatic conditions. From the above relation, it is at once evident that, for systems of the prior art, one cannot tolerate a significant volume change upon discharge without having the extraction of energy from the precharged accumulator be accompanied by a significant internal pressure change. This pressure change, besides being undesirable in itself for many types of hydraulic loads, will be associated with a decrease in available energy, inasmuch as the available or potential energy is proportional to pressure.

A novel feature of the system according to the invention is that, in contrast to conventional hydraulic energy storage power supplies wherein only a small fraction of the accumulator content may be used if reasonably constant pressure is desired across the load, nearly the entire volume capacity of the system may be utilized without

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sacrificing pressure regulation. As a result, the practical storage capability for a given size power supply is increased by nearly an order of magnitude over that achieved by the conventional accumulator arrangement.

In accordance with the invention, the relatively constant pressure energy available by virtue of the head of sea water in existence above the submerged power supply is employed in conjunction with a low pressure reservoir whose internal pressure is maintained at a low value in comparison with the ambient sea pressure. In a typical arrangement, a first reservoir is connected in the high pressure side of the system and includes a vessel having two regions separated by a flexible member which performs as a barrier to isolate hydraulic fluid from sea water. One of these regions is adapted to receive hydraulic fluid, while the other region is exposed to sea water at ambient pressure. A second or low pressure reservoir is located on the low pressure side of the system and typically takes the form of a pressure vessel which can support the ambient sea pressure, and which includes a further flexible barrier isolating a region containing gas such as nitrogen from a region containing hydraulic fluid. The latter region is connected to the low pressure side of the hydraulic system.

Located between the two reservoirs is normally a load which is driven by the pressure differential between the two reservoirs. Connected also between the two reservoirs is, typically, a pump which can extract hydraulic fluid from the low pressure reservoir and deliver it at relatively low energy rate to the high pressure reservoir.

A normal operating cycle might proceed as follows. During a time interval when the load is not energized, meaning that no hydraulic flow through the load device occurs, the pump removes residual fluid existing in the low pressure reservoir, and delivers this fluid to the high pressure reservoir, leaving the available volume of the low pressure reservoir predominantly gas-filled. The load device may then be energized allowing hydraulic fluid to flow from the high pressure reservoir through the load to the low pressure reservoir. The rate of energy delivery to the load will depend upon the pressure differential between the two reservoirs and the hydraulic flow rate demanded by the load device.

When the low pressure reservoir is nearly filled with hydraulic fluid and the gas therein compressed to a nominally minimum volume, the load flow is stopped and the pump again begins to exhaust the fluid now contained in the low pressure reservoir, returning it to sea pressure head.

The load may accept energy from the reservoir system at high energy rate for a relatively short interval of time, and the pump may recharge the system at a low energy rate over a correspondingly longer interval of time. The ratio of the discharge to charge time is normally called the duty cycle of the system, and is inversely proportional to the ratio of energy delivery rate to energy charge rate.

In contrast with conventional accumulator energy storage techniques wherein the stored potential energy is dependent on gas pressure and will therefore change in proportion to the volume of fluid extracted from the accumulator, in the system of the present invention the stored potential energy resides in the constant sea pressure head which, for all practical purposes, constitutes an infinite reservoir of potential energy. The low pressure reservoir is intended, for purposes of the invention, to act as a pressure release. Its potential energy per unit volume, even under conditions of minimum nominal gas volume, is small, compared with the potential energy per unit volume associated with the sea pressure head. For purposes of illustration, it may be assumed that the storage system is located in the vicinity of 3000 feet below the surface of the sea where the ambient pressure is 1500

p.s.i. and further that the internal pressure of the low pressure reservoir is at atmospheric pressure (15 p.s.i.) when the system is charged (i.e., when the low pressure reservoir is primarily gas-filled). If upon energizing the load, flow into the low pressure reservoir continues until the gas volume has been reduced to 10% of its initial volume, then the internal pressure of the gas will have increased from 15 p.s.i. to approximately 150 p.s.i. The final pressure in the low reservoir is thus only 10% of the total available pressure from the sea pressure head, yet 90% of the volume of the low pressure reservoir has been displaced by working fluid. In conventional accumulator practice, only 10% of the gas volume within the accumulator may be utilized if the load pressure is not to change more than 10%.

This example illustrates the significantly greater total energy capacity of a hydraulic energy storage system of a given physical size which can utilize a source of constant potential or pressure energy such as the sea pressure head, and which incorporates a highly compliant low pressure reservoir which, because of its low initial pressure, can be filled with fluid to nearly its full volume without significantly altering the available pressure head.

In some instances it may be practical to employ sea water as the operative fluid; in these circumstances the barrier and associated vessel on the high pressure side of the system may be removed.

Whereas the low pressure reservoir has been described as including a compliant gas to provide pressure release characteristics, in some applications where discharge time requirements are particularly short, the relatively smaller compliance of a liquid may be utilized. In this instance, the storage system becomes an all liquid system with the attendant advantages of greater potential reliability and longer life.

In applications where long term repetitive cycling is unnecessary, the pump circuitry may be eliminated and the storage supply may be submerged to design depth from the surface with the submerged low pressure reservoir at atmospheric pressure. The operation of submerging the source automatically establishes the potential energy head which is to be used and the equipment may be either expended or brought back to the surface for recharge at the end of the discharge cycle.

Other objects and features of the invention will become apparent upon reference to the following description and drawings wherein:

FIG. 1 is a schematic diagram of an energy storage power supply using the sea pressure head as a high pressure reservoir;

FIG. 2 is a cross-sectional view of a modification of the system shown in FIG. 1;

FIG. 3 is a diagram of a system using sea water as the operative fluid for the load; and

FIG. 4 is a diagram of a system wherein the pump circuitry shown in FIGS. 1-3 is eliminated and the potential energy head is established by the operation of submerging the system.

Referring to the drawing, the energy storage power supply of FIG. 1 includes a low power pump 10 for circulating hydraulic fluid, a load 15 through which hydraulic fluid flows and across which the system supply pressure is to be developed, and a pair of reservoirs 18 and 27 which are submerged at approximately the same depth in the sea or some other large body of liquid. Each of these reservoirs takes the form of a vessel into which a hydraulic fluid can be introduced to displace either a compliant gas or sea water, the gas or sea water normally being separated from the hydraulic fluid by a sealed piston or by a closed flexible diaphragm. The reservoir 18 is connected in the high pressure line 19, while the reservoir 27 is connected in the low pressure or discharge line 20. A portion of the wall of reservoir 18 is apertured to permit entrance of sea water at ambient pressure into compartment 21. This reservoir further includes a flexible

barrier 23 made of a thin sheet of rubber, neoprene plastic or the like which isolates the hydraulic fluid in compartment 24 from the sea water, but which permits sea pressure head to be existent at all times at the upstream or inlet port or terminal 25 of the hydraulic load 15.

The low pressure reservoir 27 is a pressure vessel connected to the discharge port or terminal 29 of the load. Within reservoir 27 a flexible barrier 33 separates the hydraulic fluid in fluid compartment 31 from the gas-filled compartment 34. Flexible barrier 33 is also made of a compliant nonpervious material such as used in the flexible barrier 23. The pump 10 removes hydraulic fluid from the fluid compartment 31 of reservoir 27 until the internal pressure of reservoir 27 is near sea level (atmospheric) pressure, and delivers the hydraulic fluid at sea pressure head to reservoir 18. An unloading valve 38 and check valve 39 may be interposed in the hydraulic circuit of the pump to unload the pump once the desired pressure in reservoir 27 is achieved. Normally, the unloading valve 38 and check valve 39 will allow flow from the pump to be delivered directly from reservoir 27 to high pressure reservoir 18. However, when the internal pressure of reservoir 27 has been reduced to some prescribed value relative to sea pressure head, the unloading valve diverts the pump flow to return path 43 at negligible pressure drop, and check valve 39 blocks the hydraulic fluid in reservoir 18 at sea pressure head from flowing back into the unloaded pump circuit. The unloading valve 38 senses the total pressure difference between the two reservoirs 18 and 27 by means of pilot connection 42 to the high pressure line 19 and return connection 43 to the low pressure line 58.

Load 15 may include its own control circuitry, operated by electrical connections 100, for example, which could be used to shut off load flow during the charge cycle. Alternatively, separate control elements such as solenoid valve 36 and/or flow control valve 41 may be included in the discharge line 20 to provide flow control and flow switching functions.

During a typical operating cycle, once the reservoir 27 has been essentially evacuated of hydraulic fluid by pump 10, the system is in a charged condition, the pressure in reservoir 27 is at a predetermined minimum value, and the pump is unloaded by means of unloading valve 39. Either by applying excitation to the load flow control circuit 100 or to the solenoid of valve 36, flow through the load circuit will occur at a pressure drop corresponding essentially to the pressure difference between reservoirs 18 and 27. Flow power will then be delivered to the load at a level dependent upon the aforesaid pressure drop and the controlled rate of fluid volume flow. At some time prior to the exhaustion of hydraulic fluid from reservoir 18 or to the filling of reservoir 27 with hydraulic fluid, the load flow is shut off.

Following the initiation of the discharge cycle, and as reservoir 27 begins to fill with hydraulic fluid, thereby causing its internal pressure to increase, unloading valve 38 transfers the pump output from the unloading line 43 to the charging circuit 59 feeding the high pressure reservoir 18. The charging cycle may thus commence prior to the completion of the discharge cycle, and continue following the completion of the discharge cycle until reservoir 27 is again essentially evacuated of hydraulic fluid and the system is fully charged.

If the pump 10 extracts fluid from reservoir 27 essentially continuously at a low energy rate, while the load 15 accepts energy from the power supply periodically at high energy rate for short time intervals, the electrical power supplied to the pump need be only approximately the peak power delivered to the load times the fractional duty cycle.

Although the unloading valve 38 and check valve 39, as shown in FIG. 1, or suitable equivalents thereof, would normally be employed in circumstances where the system can be fully charged prior to the initiation of the next

discharge cycle, their inclusion in the hydraulic circuit is by no means essential for all operating modes. For example, if the discharge repetition rate is constant, it may be found desirable to let the pump operate continuously and to choose the pumping rate, discharge flow rate, repetition rate and duty cycle so that the discharge cycle occurs immediately following the charging of the system to a prescribed valve (i.e., following the removal of a predetermined amount of fluid from the low pressure reservoir). Alternatively, a simple pressure differential switch sensing the pressure difference between the two reservoirs might be employed to initiate and terminate a discharge cycle. In this instance, the pump could also be turned on or off as controlled by the pressure differential switch.

A typical structural arrangement for use in a system such as illustrated schematically in FIG. 1 is shown in FIG. 2. The elements of FIG. 2 corresponding to those in FIG. 1 are denoted by like reference numerals. A pair of generally hemispherical shells 61 and 62 are joined together to form a low pressure reservoir 27. Reservoir 27 includes a flexible barrier 33 for dividing the reservoir into an upper portion 34 containing a gas, such as nitrogen, and a lower portion 31 adapted to receive hydraulic fluid through a port 55. An annular cylindrical high pressure reservoir 18, secured to the shell 62 of reservoir 27 as by bolts 66, contains two compartments 21 and 24 separated by a flexible barrier 23. The outer portion of the wall of reservoir 18 is apertured to admit sea water under pressure into compartment 21. Compartment 24 is filled with hydraulic fluid and is subjected to the sea pressure head through the flexibility of barrier 23.

A pump 10 is driven by an appropriate motor 70 centrally mounted within the central cylindrical region 71 to the inner wall 72 of reservoir 18. When control valve 36 is closed, hydraulic fluid is removed by pump 10 from the compartment 31 of low pressure reservoir 27 by way of port 57 and fluid conduit 58 exposed to the central region 71. The fluid then flows through the pump 10, thence through unloading valve 38 and check valve 39 and passage 77 into the hydraulic fluid compartment 24 of high pressure reservoir 18. Subsequently, when control valve 36 is open, the hydraulic fluid passes out through line 19, load 15, and control valve 36 to the line 20 leading to the low pressure reservoir 27.

The hydraulic system of FIGS. 1 and 2 has been illustrated as a closed system with barriers isolating the operative hydraulic fluid from sea water and the entrained gas in the low pressure reservoir. This procedure may generally be preferable as the operative fluid may then be selected to provide optimum characteristics in terms of lubricity, viscosity and corrosion protection from the point of view of the pump, control and load elements. In some instances, however, it may be practical to employ sea water as the operative fluid and in these circumstances the barrier 23 and high pressure reservoir 18 may be removed to admit sea water directly into the hydraulic system; a system of this type is shown in FIG. 3. In the system of FIG. 3, the entire high pressure reservoir 118 is receptive of sea water and the fluid compartment 31 of low pressure reservoir 27 contains sea water rather than hydraulic fluid. For simplicity, the pump and fluid control means has been shown in FIG. 3 by a reference numeral 101. It should be understood that many variations of pumps and valving are feasible. The pump and fluid control means 101 exhaust the sea water from the low pressure reservoir 27 directly into the sea through apertures in the high pressure reservoir 118. The exhaust pump and fluid control means 101 set or maintain the low pressure reservoir 27 in a state of low pressure relative to a high hydrostatic pressure on the perforated reservoir 118. The difference in fluid pressure between the low pressure reservoir 27 and the high pressure reservoir 118 is a measure of available fluid energy for the load 15.

Whereas the low pressure reservoir 27 of FIGS. 1-3 has

been described as including a compliant gas to provide pressure release characteristics, in some applications where discharge time requirements are particularly short, the relatively smaller compliance of a liquid may be utilized. In this instance, the storage system becomes an all liquid system with the attendant advantages of greater potential reliability and longer life. Such a storage system would differ from that shown in FIGS. 1-3 only in that the barrier 33 in the low pressure reservoir 27 of FIGS. 1-3 and the gas in the region 34 of the low pressure reservoir would be eliminated so that the entire volume of reservoir 27 may be filled with the operative fluid.

The energy storage system of FIGS. 1 and 2 has been illustrated with typical charging circuitry, namely, a pump and unloading valve arrangement, to enable repetitive charge and discharge cycles to occur. The pump may be driven by a submersible electric motor, connected by a cable to an electric power source which may be at a shore or ship location. Alternatively, submerged, unattended power sources, such as a nuclear reactor or internal combustion engine, may be employed. In the latter case, in the event mechanical power is available directly from the power source, direct coupling to the pump may be appropriate.

In applications where long term repetitive cycling is not necessary, the pump circuitry may be eliminated. For example, as shown in FIG. 4, the storage supply including the high pressure reservoir 18 could be submerged to design depth from the surface with the submerged low pressure reservoir 27 which may be at atmospheric (sea level) pressure. The operation of submerging the system automatically establishes the potential energy head which subsequently is to be employed. The control valve 36 regulates the flow of fluid from the high pressure reservoir 18 through the load 15 to the low pressure reservoir 27. The flow of fluid from the high pressure reservoir 18 to the low pressure reservoir 27 is considered the discharge cycle of the system. At the conclusion of the full discharge cycle, when the low pressure reservoir 27 is fluid-filled, the equipment may be expended or brought back to the surface for recharge.

What is claimed is:

1. In a hydraulic energy storage system for supplying hydraulic flow energy to a load having high and low pressure terminals upon passage of a fluid through said load, a fluid medium of relatively large volume, means for hydraulically coupling said high pressure terminal to said fluid medium in a region of high pressure established at a predetermined depth within said fluid medium of relatively large volume, and a low pressure reservoir coupled to said low pressure terminal for receiving said fluid from said load.

2. In a hydraulic energy storage system for supplying hydraulic flow energy to a load having high and low pressure terminals upon passage of a fluid through said load, a fluid medium of relatively large volume, means for hydraulically coupling said high pressure terminal to said fluid medium in a region of high pressure established at a predetermined depth within said fluid medium of relatively large volume, and a low pressure reservoir coupled to said low pressure terminal for receiving said fluid from said load, said low pressure reservoir being submerged in said fluid medium at substantially said predetermined depth.

3. In a hydraulic energy storage system for supplying hydraulic flow energy to a load having high and low pressure terminals upon passage of a fluid through said load, a fluid medium of relatively large volume, means for hydraulically coupling said high pressure terminal to said fluid medium in a region of high pressure established at a predetermined depth within said fluid medium of relatively large volume, a low pressure reservoir coupled to said low pressure terminal for receiving said fluid from said load, said low pressure reservoir being submerged in said fluid medium at substantially said predetermined

depth, and control means for selectively permitting transfer of fluid through said load into said low pressure reservoir.

4. In a hydraulic energy storage system for supplying hydraulic flow energy to a load having high and low pressure terminals upon passage of fluid through said load, a fluid medium of relatively large volume, means for hydraulically coupling said high pressure terminal to said fluid medium in a region of high pressure established at a predetermined depth within said fluid medium of relatively large volume, a low pressure reservoir connected to said low pressure terminal for receiving said fluid from said load, and control means for selectively permitting transfer of fluid through said load into said low pressure reservoir.

5. In a hydraulic energy storage system for supplying hydraulic flow energy to a load having high and low pressure terminals upon passage of fluid through said load, a fluid of relatively large volume, means for hydraulically coupling said high pressure terminal to said fluid medium in a region of high pressure established at a predetermined depth within said fluid medium of relatively large volume, a low pressure reservoir connected to said low pressure terminal and submerged in said fluid medium at substantially said predetermined depth, and control means for selectively permitting transfer of fluid from said fluid medium through said load into said low pressure reservoir.

6. In a hydraulic energy storage system for supplying hydraulic flow energy during one portion of an operating cycle to a load having high and low pressure terminals, said high pressure terminal being hydraulically coupled to a relatively large body of fluid at a predetermined depth at which a desired high pressure is attained, a low pressure reservoir connected to said low pressure terminal, fluid from said body of fluid being transferred through said load to said low pressure reservoir during one portion of said operating cycle, and a fluid pump for transferring fluid from said low pressure reservoir to said body of fluid during the remaining portion of said operating cycle.

7. In a hydraulic energy storage system, a load adapted to convert hydraulic flow energy into energy of another form during a portion of each operating cycle in response to fluid flow therethrough, said load having high and low pressure terminals, said high pressure terminal being opened and positioned in a relatively large body of fluid at a predetermined depth at which a desired high pressure is attained, a low pressure reservoir hydraulically coupled to said low pressure terminal and submerged to substantially said predetermined depth, and means for transferring fluid through said load into said low pressure reservoir during said portion of said operating cycle, said reservoir having a fluid compartment capable of volumetric change as fluid is transferred to said reservoir.

8. In a hydraulic energy storage system, a load adapted to convert hydraulic flow energy into energy of another form during a portion of each operating cycle, said load having high and low pressure terminals, a high pressure reservoir and a low pressure reservoir hydraulically coupled respectively to said high pressure terminal and said low pressure terminal, said reservoirs each including hydraulic fluid compartments capable of volumetric change, and means for controlling transfer of hydraulic fluid from said high pressure reservoir to said low pressure reservoir during said portion of said operating cycle until said low pressure reservoir is substantially, filled with hydraulic fluid, said high pressure reservoir being submerged in a fluid medium of relatively large volume to a depth at which a relatively high pressure exists, at least a portion of said high pressure reservoir being exposed directly to said fluid medium to maintain the pressure of said hydraulic fluid in said fluid compartment of said high pressure reservoir substantially constant, the variation in pressure of the hydraulic fluid in said low pressure reservoir during said transfer of hydraulic fluid being small com-

pared with the variation in pressure of said hydraulic fluid in the fluid compartment of said high pressure reservoir.

9. In a hydraulic energy storage system, a load adapted to convert hydraulic flow energy into energy of another form once during each operating cycle, said load having high and low pressure terminals, a high pressure reservoir and a low pressure reservoir hydraulically coupled respectively to said high pressure terminal and said low pressure terminal, and means for transferring hydraulic fluid from one reservoir to another and back during each operating cycle, said reservoirs having hydraulic fluid compartments capable of volumetric change as hydraulic fluid is transferred between reservoirs, said high pressure reservoir being submerged in a fluid medium of relatively large volume to a depth at which a relatively high pressure exists, at least a portion of said high pressure reservoir being exposed directly to said fluid medium to maintain the pressure of said hydraulic fluid in said fluid compartment of said high pressure reservoir substantially constant.

10. In a hydraulic storage system as recited in claim 9, said reservoirs being joined together to form an integral housing.

11. In a hydraulic energy storage system having a high pressure line, a low pressure line and a load adapted to convert hydraulic flow energy into energy of another form connected across said lines, a hydraulic pump for circulating fluid in said system, a first reservoir connected to said low pressure line and exposed to discharge fluid pressure from said load, a second reservoir connected to said high pressure line and submerged in a fluid medium to a depth at which a relatively high pressure exists compared with said discharge fluid pressure, each of said reservoirs having a first portion adapted to receive said hydraulic fluid and a second portion separated from said first portion by a flexible fluid barrier, said second portion of said first reservoir being filled with a compliant gas, and said second portion of said second reservoir communicating with said fluid medium.

12. In a hydraulic energy storage system having a high pressure line and a low pressure line and a load adapted to convert hydraulic flow energy into energy of another form connected across said lines, a hydraulic pump for circulating a first hydraulic fluid in said system, a first reservoir connected to said low pressure line, a second reservoir connected to said high pressure line and submerged in a fluid second medium to a depth dependent upon the desired pressure difference between said high and low pressure lines, each of said reservoirs having a first portion adapted to receive said first hydraulic fluid and a second portion separated from said first portion by a flexible fluid barrier, said second portion of said first reservoir being filled with a compliant gas, said second portion of said second reservoir being open to said second fluid medium, control valving means for permitting said first hydraulic fluid to be transferred from the first portion of said first reservoir to the first portion of said second reservoir in the absence of a control signal, said valving means including means responsive to the attainment of a predetermined pressure difference between the pressure at said first and said second reservoirs to discontinue said first hydraulic fluid transfer and to unload said pump, and means responsive to the presence of said control signal for permitting said first hydraulic fluid to be removed from said first portion of the second reservoir and to be circulated through said load to the first portion of said first reservoir.

13. A system as recited in claim 12 wherein said load includes an electro-hydroacoustic transducer placed in operable condition when receptive of said control signal.

14. In combination, a hydraulic circuit through which is circulated a hydraulic fluid, a hydraulic load having high and low pressure terminals connected in said hydraulic circuit, first and second reservoirs connected respectively to said low and high pressure terminals of said

load, said second reservoir being submerged in a fluid medium to a depth at which said high pressure exists, said reservoirs each being divided into first and second compartments by expansible means, said first compartment of said reservoirs being arranged to receive said hydraulic fluid, said second compartment of said second reservoir being exposed to said fluid medium whereby the pressure within said first compartment of said second reservoir is maintained substantially constant at said high pressure, said second compartment of said first reservoir being filled with a compliant gas at relatively low pressure compared with said high pressure, and means for permitting said fluid to pass from said second reservoir to said first reservoir through said load during a portion of an operating cycle in response to a control signal, said load being adapted to convert hydraulic flow energy into energy of another form during flow of fluid therethrough.

15. In combination, a hydraulic circuit through which is circulated a hydraulic fluid, a hydraulic load having high and low pressure terminals connected in said hydraulic circuit, control means for permitting said hydraulic fluid to pass through said load during a portion of an operating cycle in response to a control signal, said load being adapted to convert hydraulic fluid flow energy into energy of another form during flow of said hydraulic fluid therethrough, first and second reservoirs connected respectively to said low and high pressure terminals of said load, said second reservoir being submerged in a fluid medium to a depth at which said high pressure exists, said reservoirs each being divided into first and second compartments by a yielding fluid barrier, said first compartment of said reservoirs being arranged to receive said hydraulic fluid, said second compartment of said second reservoir being exposed to said fluid medium whereby the pressure within said first compartment of said second reservoir is maintained substantially constant at said high pressure, said second compartment of said first reservoir being filled with a compliant gas at a relatively low pressure compared with said high pressure, and means for transferring said hydraulic fluid from said first reservoir to said second reservoir during absence of flow of said

hydraulic fluid through said load until said pressure at said first reservoir falls to said low pressure.

16. In combination, a hydraulic circuit through which is circulated a hydraulic fluid, a hydraulic load having high and low pressure terminals connected in said hydraulic circuit, control means for permitting said hydraulic fluid to pass through said load during a portion of an operating cycle in response to a control signal, said load being adapted to convert hydraulic fluid flow energy into energy of another form during flow of said hydraulic fluid therethrough, first and second reservoirs connected respectively to said low and high pressure terminals of said load, said second reservoir being submerged in a fluid medium to a depth at which said high pressure exists, said reservoirs each being divided into first and second compartments by a yielding fluid barrier, said first compartment of said reservoirs being arranged to receive said hydraulic fluid, said second compartment of said second reservoir being exposed to said fluid medium whereby the pressure within said first compartment of said second reservoir is maintained substantially constant at said high pressure, said second compartment of said first reservoir being filled with a compliant gas at a relatively low pressure compared with said high pressure, and means for transferring said hydraulic fluid from said first reservoir to said second reservoir during absence of flow of said hydraulic fluid through said load until said pressure at said first reservoir falls to said low pressure, said control means including means for discharging said hydraulic fluid from the first compartment of said second reservoir through said load to said first reservoir during the presence of said control signal.

17. In a hydraulic storage system as recited in claim 15, said yielding fluid barrier being a thin sheet of a compliant nonpervious material.

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