June 4, 1968 D. ROSENBERG 3,386,388

HYDRAULICALLY ACTUATED PUMP

Filed June 22, 1966

FIG. 1

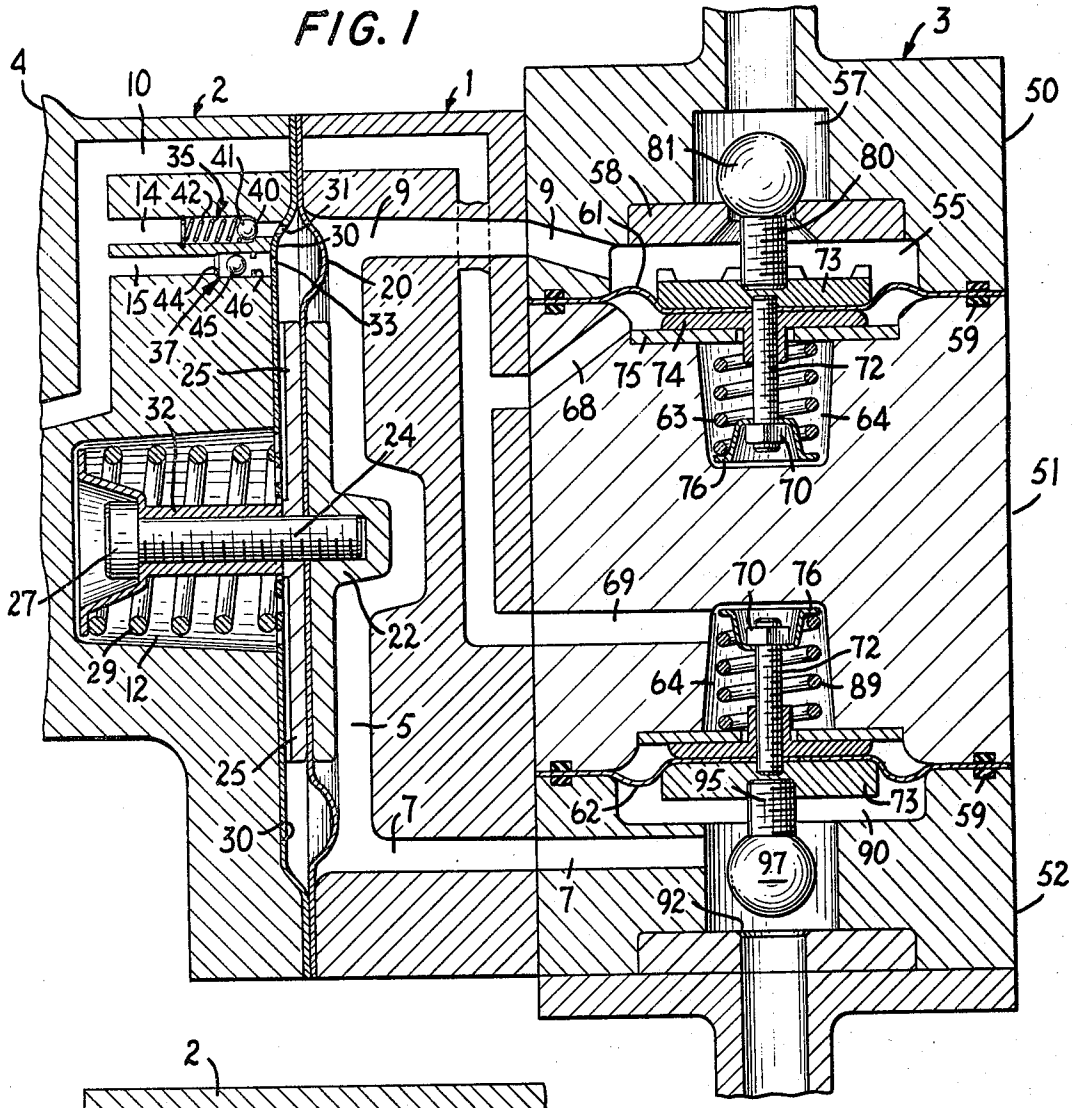
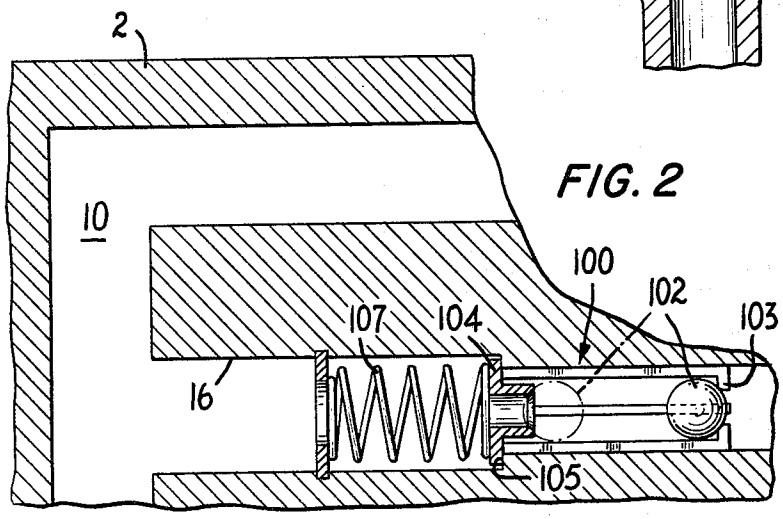


FIG. 2



United States Patent Office 3,386,388 Patented June 4, 1968

3,386,388

HYDRAULICALLY ACTUATED PUMP

David Rosenberg, 12 Francis Court, Glen Cove, N.Y. 11542

Filed June 22, 1966, Ser. No. 559,547
14 Claims. (Cl. 103—152)

ABSTRACT OF THE DISCLOSURE

A hydraulically actuated diaphragm pump is provided having a check valve in a line from the hydraulic source to the chamber adjacent the diaphragm. A second hydraulic line connects the pump valve with the hydraulic source. The check valve creates a differential pressure between the chamber and the second hydraulic line on a stroke of the pump to maintain the sequence of movement between the diaphragm and the pump valve.

This invention relates to fluid devices, and more particularly to fluid displacement pumps of the type adapted to fluid actuation.

Metering and proportioning pumps for the movement of chemical solutions and the like are known, in which a pumping impulse is provided to the pumping mechanism in the form of a fluid impulse, such as an oscillating flow of hydraulic fluid in an actuating line connected to the pumping mechanism. This is a convenient arrangement, because the volume and the frequency of the pump strokes can be very accurately regulated by adjustment of the source of the fluid impulses.

The pumping mechanism itself is frequently a diaphragm pump actuated by the pumping impulses, and provided with inlet and outlet valves for the control of the flow of the pumped liquid.

Since the pumped liquid frequently is a chemical additive, which may often be in the form of a slurry, and frequently is in the form of a dissolved or diluted material, it is common for the pumping mechanism to be required to handle a liquid suspension of undissolved or insoluble particles, especially when it has pumped down toward the end of a batch or container-full of the additive material. Such particles are usually limited in size to those smaller than the mesh dimensions of an appropriate inlet screen, so that blockage of the pump by a single large particle seldom occurs. Many of the suspended solids which it is desired to pump, however, display the inconvenient property of breaking out of suspension near regions of turbulence, coagulating and building up on nearby parts of the pump.

When this occurs on the pump valves, and especially on the inlet valve, it causes it to leak, thus destroying the metering accuracy of the pump, and it is not unusual for it to cause the inlet valve to refuse to close at all during some strokes of the pump, thus destroying its effectiveness. Similar deposits can also build up on the outlet valve.

Even in cases where such extreme consequences do not occur, many of these suspensions, such as those of talc, chalk or fuller's earth, or diatomaceous earth, are highly abrasive, and result in a rapid wear and destruction of the pump valves and seats due to the erosive effect of the suspension when it flows through a partly closed valve at high velocity.

Another difficulty experienced in the construction of metering pumps is that if accuracy of measurement is desired, the pump valves must be designed to be as small as feasible. This is because, since they are necessarily provided with a resilient seal, the precise closed position of the valve is always somewhat in doubt because of the compressibility of the seal, which allows the valve to assume different positions according to the pressure exerted upon it. Minimizing the size of the valve thus reduces but cannot eliminate the changes in pumping chamber volume arising from this cause, and accentuates all of the aforementioned difficulties due to suspended material in the pumped fluid, both because of the difficulty of constructing such a small part with precision, and because of increased flow velocity and consequent erosion which such small size requires.

Slurry pumps are known which overcome many of these difficulties by providing pressure-actuated valves which are of relatively large dimensions, and are driven between open and closed positions according to the fluid pressure impulse applied in a separate hydraulic system, which is also in fluid pressure connection with the hydraulic chamber of the pump to actuate the pump. Such pumps are shown in U.S. application Ser. No. 396,794, filed on Sept. 4, 1964, now U.S. Patent No. 3,256,825.

Pressure-actuated valves can be formed of a size sufficient to ensure accurate and reliable operation in pumping slurries, and to reduce the flow through the valve to the point where excessive deposition of slurried particles does not occur. Moreover, it is possible to form the valves and seats of a hard material which is highly resistant to abrasion and which can be formed with sufficiently sharp edges to cut through any deposits which may form, thereby having a self-cleaning action.

An even greater degree of accuracy has been obtained by having one of the valves hydraulically actuated and biased (such as by a spring) against the actuating hydraulic pressure to keep the valves open or closed, as desired. Generally, the pump inlet valves are biased open, and the outlet valves are biased closed. Biasing is especially important when pumping highly concentrated, abrasive slurries. However, the accuracy of the pump can be seriously impaired if the other valve is operated directly by the pumped slurry. Particles more readily are deposited in the valve, preventing the valve from fully closing, when the operation of the valve is dependent upon the pressure exerted against the upstream face of the valve by the pumped slurry.

When both valves are operated by a separate hydraulic system, the problems of clogging and sticking of the valves are substantially eliminated, even when pumping highly concentrated abrasive slurries. However, other problems are encountered when both the inlet and the outlet valves, as well as the pumping member, are biased and hydraulically activated. All of the bias members have to be very precisely calibrated so that the valves and the pump are actuated by the same hydraulic pressure at the same time, i.e. the inlet valve open or close, the outlet valve close or open and the pumping member expand or contract, respectively, at the same hydraulic pressure in the hydraulic pressure system at the same time. The problems of maintaining such exact response in commercial operations are overwhelming. Furthermore, the bias means, such as springs, normally do not all wear at the same rate, and inaccuracies soon develop during operation, requiring constant adjustment of the pump settings.

It has now been found, however, that hydraulically-actuated, biased inlet and outlet valves can be used together in a hydraulically-actuated pump with only approximately calibrated bias means, wherein the exact force exerted by each of the bias means is not critical to the accuracy of the pump. Furthermore, according to this invention, the valves and pumping member can be actuated in any desired order.

The bias members are preferably calibrated so that on the compression stroke of the pump a relatively low hydraulic pressure actuates the inlet valve to close, the

same or a relatively higher hydraulic pressure actuates the outlet valve to open and a still higher hydraulic pressure, the highest of the three, actuates the pumping member. According to this invention, means are also provided such that during the intake stroke of the pump the outlet valve closes first, at the relatively highest hydraulic pressure, the inlet valve opens simultaneously or subsequently at the same or at a relatively lower hydraulic pressure, and the pumping member is actuated last at the relatively lowest hydraulic pressure. The term "effective hydraulic pressure" as used herein refers to the pressure differential across the pressure-responsive member in question, such as a diaphragm or piston exposed on one side to hydraulic system pressure and on the other side to pump system pressure.

The invention accordingly provides a pump for supplying fluid through a line compising, in combination, a pump chamber; a pressure chamber; and a diaphragm therebetween normally biased towards a first position; a fluid connection through the pump chamber for flow of fluid to and from the chamber; a fluid pressure-responsive valve having open and closed positions and disposed across the line of fluid flow through the pump chamber for controlling the flow of fluid therein, said valve being normally biased towards one of the open and closed positions; a hydraulic system comprising a source of hydraulic pressure; a first hydraulic fluid connection to the pressure chamber for flow of pressure fluid to the pressure chamber for movement of the diaphragm away from the first position to pump fluid through the pump chamber and the fluid connection therethrough; a second hydraulic fluid connection communicating the fluid pressure-responsive valve with one of the pressure and pump chambers of the pump for movement of the valve away from its first position to the other of its positions in response to fluid pressure in the chamber; the valve and the diaphragm being moved in a predetermined sequence by predetermined hydraulic pressures developed by the hydraulic source in the second hydraulic fluid connection and in the pressure chamber, respectively; and regulating means in said first hydraulic fluid connection producing on alternate strokes of the pump a pressure difference between the pressure chamber and the second hydraulic fluid connection greater than the difference between the effective bias strength acting on the valve and the effective bias strength acting on the diaphragm, thereby maintaining the sequence of movement of the valve and the diaphragm upon each successive stroke of the pump.

The term "stroke" is intended to describe a complete movement of the diaphragm in a single direction between its extreme positions, i.e. the intake stroke and the exhaust stroke.

Preferably, the regulating means comprises check valve means in the first hydraulic fluid connection, bias means operatively connected to said check valve means in a manner permitting the valve to open to flow in one direction at a substantially zero pressure drop across the valve and permitting the valve to open to flow in the other direction only at a predetermined pressure drop across the valve, the effective strength of the bias means acting upon the check valve being greater than the difference between the effective bias strength on the diaphragm and the effective bias strength on the valve.

Thus, on the pressure stroke, upon increase in hydraulic fluid pressure in the hydraulic system, the increased pressure is communicated to the pressure-responsive valve which is actuated to its second position, i.e. the inlet valve to a closed position or the outlet valve to an open position, and then actuates the diaphragm. If the valve is an inlet valve, the bias means acts to hold it open, and the valve is driven to a closed position upon increase in pressure in the pressure chamber. If the valve is an outlet valve, the bias means acts to hold it closed, and it is driven to an open position, upon increase in pressure in the pressure chamber. On the intake stroke, when the hydraulic pressure is relaxed, the valve is first moved back to its first position, i.e. the outlet valve is first closed or the inlet valve first opened, and then the diaphragm moves to draw in fluid to the pump chamber.

Preferably, the inlet and outlet valves are hydraulically actuated and biased. The bias means acting on the diaphragm as well as those acting on both valves can be so set that they are actuated at the same pressure in the hydraulic system provided by the pulse means. In the preferred embodiment, where both valves are hydraulically actuated and biased, both valves are preferably actuated before the diaphragm on both strokes, and the inlet valve is preferably actuated at a lower hydraulic pressure than the outlet valve, for greatest accuracy of operation. As used hereafter, the "effective strength" of the bias means and the "effective bias strength" refers to the effective hydraulic pressure required to overcome the bias means.

The regulating biased check valve means can include a single double-seating valve or a pair of check valves, one being free to open to flow in one direction, i.e., unbiased, and the other being biased against opening to flow in the other direction, located in parallel hydrau'ic fluid connections between the hydraulic pressure source and the pressure chamber of the pump.

The direction in which the biased check valves operate depends upon the relative effective strength exerted by each of the bias means acting on the diaphragm and on the valve. If the bias member on the diaphragm has the greatest effective strength, the check valve of zero pressure is opened when a positive pulse of hydraulic pressure is applied on the pressure stroke of the pump, i.e. when hydraulic fluid flows into the pressure chamber of the pump. The biased valve is opened during the reverse flow, when the hydraulic pulse is relaxed and fluid flows out of the hydraulic chamber. The biased check valve operates only after the difference between the hydraulic pressure in the rest of the hydraulic system and in the pressure chamber, or the pressure drop across the check valve, is greater than the effective strength of the check valve bias means. If the bias means on the valve is stronger than that on the diaphragm, the check valves act in the reverse direction.

The bias means on the check valve need only be greater than the difference between the effective strengths of the valve bias means and the pump bias means. The inlet or the outlet valve is thereby closed or opened, respectively, prior to the movement of the diaphragm on the pressure stroke and is similarly actuated to be opened or closed respectively prior to the movement of the diaphragm on the intake stroke. This arrangement is suitable when one or both of the inlet and outlet valves are biased and actuated hydraulically.

Preferably, when both the inlet and the outlet valves and the diaphragm are biased and hydraulically actuated, the inlet valve bias means has the lower effective force. However, if desired, these valve bias means can have substantially equal effective strengths.

The pump valves as used in this invention generally include a valve body and a valve seat disposed across the line of flow through the pump chamber. The valve body is mounted for to and fro movement between open and closed positions away from and in contact with the valve seat. Bias means are connected to the valve body to retain it in either an open or closed position. Fluid pressure-responsive means are attached to the valve body for moving it against the action of the bias means and the fluid pressure responsive means is in fluid connection with one of the chambers of the pump, usually the pressure chamber.

Preferably, the source of hydraulic pressure is a pulsing means such as a piston pump having means to supply on each pressure stroke of the piston a known volume of hydraulic fluid to the hydraulic chamber to distend the diaphragm. The preferred pump is an adjustable recipro-

cating piston pump of the type shown in U.S. Patent No. 2,869,467, discussed above. In that pump, on each suction stroke of the piston, the cylinder is vented to a reservoir of oil which in turn is vented to the atmosphere. Any air or other gas which may collect in the hydraulic chamber of the diaphragm pump is thereby swept out of the cylinder into the reservoir and then to the atmosphere. The fact that the pumping cylinder is immersed in a reservoir of oil prevents any additional air from entering the hydraulic chamber during the venting. Pulsing systems other than reciprocating piston pumps are also suitable for use in the invention, such as a rotary piston pump. The "hydraulic system" of these pumps include the hydraulic pressure chamber of the pump, any conduits connecting that chamber to the pulsing means and valves, and usually, the pulsing means itself.

The pumps of the invention can include a plurality of diaphragms, in the manner, for example, shown in U.S. Patent No. 3,100,451. The pumping chamber or alternatively, the pulsing or hydraulic chamber, can, for example, be in the form of a cylinder, closed at each end by an impermeable flexible diaphragm, with the bias means always in the pulsing or hydraulic chamber or chambers. In the case of a double diaphragm pumping chamber, the tension bias means is placed outside the diaphragms, and the hydraulic liquid is supplied to the hydraulic chambers outside the diaphragms. In the case of a double diaphragm hydraulic chamber, the tension bias means is placed between the diaphragms and the hydraulic liquid is supplied to the chamber therebetween for flexing action of the diaphragms in the pumping chambers. In such a structure, two different liquids could be pumped, and one diaphragm could be stopped (an adjustable stop can be used) so that the other receives a pressure effect of a proportion of the volume of hydraulic fluid supplied, the total amount of this fluid in turn being adjusted by the effective stroke of the piston. If but one liquid is to be pumped, the valves can be manifolded so that a single outlet could be used.

The bias means is of the tension or compression type depending upon the position of the hydraulic chamber and the direction of the bias force required. Any form of bias means can be used. Coil springs, disk springs, also known as Belleville springs or washers, and resilient bushings or plugs are typical, and various embodiments thereof are shown in the drawings. These can be made of any suitable material, usually metal, such as stainless steel, carbon steel, nickel, brass and bronze, or plastic, such as rubber, synthetic rubber, polyamides, polypropylene, polyvinyl butyral, or metal coated with any inert plastic material.

The diaphragms employed in the proportioning pumps of the invention can be made of any sheet material which is sufficiently flexible and resilient to be flexed under fluid pressure, and which can be returned to normal nonflexed position when the fluid pressure is relieved, aided, in accordance with the invention, by bias means. Desirably, the diaphragm can withstand many millions of such flexures without damage.

For additional strength, the sheet diaphragm can be provided with a backing material or plate which will prevent damage due to overpressuring, and can also serve to control the amount of flexure under a given fluid pressure.

In addition, to increase flexibility, a diaphragm can be formed as a composite or multiple ply structure. Two or more flexible sheets, of the same or different material, can be laminated or clamped together to form the diaphragm. If the sheets are laminated, they can be joined together with an adhesive material, by welding or any other suitable means. The use of a laminated or clamped structure of very thin sheets increases the strength of a diaphragm of a given resiliency, thereby allowing for a greater range for flexing on each stroke of the diaphragm. The laminate is preferably designed so that the outer plies are strong in tension and the center plies strong in compression. The laminate can also be formed of materials with directional strength by alternating directions of axes in each ply. In the case of plural diaphragms, the diaphragms can all be laminated, or only one can be laminated, as desired. The laminated diaphragm can be designed to have the same or a different resiliency than the single ply diaphragm.

The configuration of the diaphragms can be selected according to the pumping requirements. For instance, the diaphragm can be of uniform thickness throughout its area. It can also be designed to be thicker at the center than at the periphery, so as to increase its resistance to flexing. The shape of the diaphragm is quite immaterial and the diaphragm can be circular, elliptical, polygonal, rectangular, square or indeed any shape, according to the design of the hydraulic or pulsing and pumping chambers. Thus, for example, the diaphragms can be made of sheet metal, such as stainless steel, Monel metal, aluminum, copper, carbon steel, brass, tin, nickel and zinc, or of a resilient plastic sheet material such as rubber, synthetic rubber, neoprene, Viton A, urea-formaldehyde, melamine-formaldehyde, phenol-formaldehyde, polymethylmethacrylate, nylon, polystyrene, polytetrafluoroethylene, polytrifluorochloroethylene, polypropylene, polyethylene, polyvinyl chloride, polyvinylidene chloride and polycarbonate resins, and epoxy resins; and fiber-reinforced laminates of any of these materials, e.g. glass fiber, cotton fiber, linen fiber and the synthetic fibers such as nylon.

The back-up plates or other materials used, if desired, for reinforcement can be made of the same or different materials. Thus, for instance, a stainless steel diaphragm can be supported by a stainless steel plate or by a plastic plate, and a rubber diaphragm can be reinforced by a stainless steel plate or by a plate made of polytetrafluoroethylene or nylon. These are merely illustrative examples, and other combinations will be apparent to those skilled in the art from the above description.

The pulsing or hydraulic fluid can be selected as desired, according to the bias means employed, and will be inert to the bias means, the diaphragm and hydraulic chamber walls. Any hydraulic fluid can be used. The hydraulic fluid can, for example, be a lubricating oil or other non-corrosive petroleum liquid, a silicone oil, or a polyalkylene glycol ether.

The pressure-responsive means acting on the valve can take any of several forms. A diaphragm is especially advantageous, and is preferred. The diaphragm can be of flexible material, such as metal, for instance, stainless steel, iron, steel, aluminum, tin, nickel-chromium alloy, or copper, or plastic, such as polyamide, polytetrafluoroethylene, polycarbonate, polystyrene, polyethylene, or polypropylene. It can be resilient, such as rubber, or synthetic rubber, or a sheet spring, such as a Belleville spring disc or washer, affixed to a piston-type or poppet valve. Reinforcing support can be provided a diaphragm of structurally weak material.

A bellows also can be used, really a form of folded diaphragm, and made of any of the above materials.

In some uses, a piston means operated in a cylinder is particularly desirable. A piston can be combined with a diaphragm to increase the surface area open to pressure actuation in one direction and thus permits high hydraulic fluid pressure for actuating the pump diaphragm without exceeding permissible valve seating pressure and/or valve diaphragm bursting pressures. Such a valve is shown in application Ser. No. 396,794, filed Sept. 4, 1964, now U.S. Patent No. 3,256,825.

The bias means for the valve include a tension or compression spring, or appropriate design and resiliency including any of the types set forth above for the diaphragm bias means. The inherent resiliency of the valve actuating member, such as a stainless steel diaphragm can be employed to like purpose. A Belleville washer can be used to retain the valve in either the open or the closed positions, to ensure return of the valve to one of such positions in response to change in fluid pressure. A magnetic pres-

sure responsive means can be used, attracted to a corresponding magnetic means at the position at which the valve is to be retained. One or both of such magnetic means can be magnets.

The drawings show several preferred embodiments of the invention.

FIGURE 1 is a sectional view of a fluid displacement pump having pressure-responsive valves constructed in accordance with the present invention, and utilizing diaphragms as the pressure-responsive means.

FIGURE 2 is a partial sectional view of an alternative form of hydraulic fluid connection between the pressure chamber and the pulsing means for FIGURE 1.

Referring to the drawings, the diaphragm pump shown in FIGURES 1 and 2 includes a pump section **1**, a hydraulic section casing **2**, a valve section casing **3** and a pulsing means section **4**. The sections **1**, **2**, **3** and **4** are held together by bolts passing through flanges not shown. Defined within the pumping section **1** are pump chamber **5** and inlet and outlet conduits **7** and **9** to the pump chamber. Also defined within the pump section is a portion of a hydraulic line **10**. Defined within the hydraulic section **2** is the hydraulic pressure chamber **12**, hydraulic line **10**, in alignment with the portion of hydraulic line **10** in the pump section **1**, and parallel hydraulic lines **14** and **15** connecting the hydraulic line **10** to the hydraulic pressure chamber **12**.

Diaphragm **20** defines one wall of the pumping chamber **5** and one wall of the hydraulic chamber **12**. The flexible diaphragm **20** is clamped between the hydraulic casing **2** and the pump casing **1**. Bolt **24** passes through a central opening in the diaphragm **20** and is threaded into a flanged nut **22** on the pumping chamber side of the diaphragm. To prevent leakage through the diaphragm, a sealing nut **25** is threaded on bolt **24** on the hydraulic chamber side of the diaphragm, and nuts **22** and **25** clamp on to the diaphragm **20**, to form a leakproof seal. At the far end of bolt **24** is the bolt head **27**.

The compression coil spring **29**, for biasing the diaphragm, is held between a perforated back-up plate **30**, also clamped at its periphery between the pump casing **1** and the hydraulic casing **2**, and the spider **32**, which is fitted between bolt head **27** and sealing nut **25**. Two perforations **31** and **33** in the back-up plate **30** are aligned with hydraulic lines **14** and **15** respectively. Thus, whenever the diaphragm **20** is flexed outwardly into the pumping chamber **5**, such movement is against the action of the spring **29**, which tends to pull the diaphragm back in the direction of the hydraulic chamber. As a result, when the hydraulic fluid pressure tending to force the diaphragm outwardly is released, the spring **29** pulls the diaphragm **20** back to the normal nonflexed position shown in FIGURE 1.

The parallel hydraulic lines **14** and **15** are provided with check valves **35** and **37**, respectively. The first check valve **35** comprises a valve seat **40**, valve ball **41** and compression spring **42** acting as the bias member. The first check valve **35** prevents any flow through line **14**, when positive pressure is applied by the pulsing means through line **10**, into the hydraulic chamber **12**. In the reverse direction, check valve **35** will permit flow from the hydraulic chamber **12** only after the pressure drop across the valve is sufficient to overcome the force of compression spring **42**.

The second check valve **37** comprises valve seat **44**, ball valve **45** and stop members **46**. The second check valve **37** permits flow into the hydraulic chamber **12** when positive pressure is applied by the pulsing means through the hydraulic line **10**. The check valve **37** prevents any flow in the reverse direction from the hydraulic chamber when the pressure pulse is released.

The valve section **3** of the pump comprises a top casing **50**, a central casing **51** and a lower casing **52**. The top, middle and bottom casings **50**, **51** and **52**, respectively, are held together by bolts not shown and any leakage at the joints is prevented by gaskets **59**, which can be formed as part of the diaphragm. The middle casing **51**, can be formed in two parts, if desired, to permit changing of the individual valves.

The top casing **50** defines an extension of the pump outlet conduit **9**, the valve chamber **55** and valve outlet conduit **57**. Valve seat **58** is inserted into the top casing **50** and defines the upper surface of the valve chamber **55**. The valve diaphragm **61** is clamped between the top and central casings **50** and **51**. The central casing **51** defines the valve hydraulic chambers **64** and hydraulic fluid lines **68**, **69** connecting the hydraulic chambers **64** to the main hydraulic fluid line **10** in the pump section **1**. Bolt **72** passes through a central opening in the diaphragm **61** and flanged nut **70** in the hydraulic valve chamber **64** is threaded on to the end of bolt **72**. To prevent leakage through the diaphragm **61**, a sealing nut **74** is threaded on to bolt **72** on the hydraulic side of the diaphragm **61** and nuts **74** and **73** clamp on to the diaphragm **61** to form a leakproof seal. Perforated plate **75** rests against an outer surface of casing **51** and serves as a stop for the diaphragm **61**. The bias spring **63** is mounted between the spider member **76** and the perforated plate **75** to bias the diaphragm in the same manner as by the bias spring **29** for the pump diaphragm **20**.

Bolt **80** is threaded into the top face of the flanged nut **73** and extends upwardly through the valve seat **58**. Ball valve **81** is secured to the top of bolt **80** at a position such that it will be held tightly against the valve seat **58** by the force exerted by bias spring **63**.

The lower casing **52** of the valve section defines the inlet valve chamber **90**, the extension of inlet line **7** connecting to the valve chamber **90**. Inlet valve seat **92** is placed into a slot in the bottom valve casing **52**.

Diaphragm **62** is clamped between the bottom and central valve casings **51** and **52**. The construction and biasing of the diaphragm **62** in the inlet valve with bias spring **89** is identical to that in the outlet valve described above.

Bolt **95** is threaded into the outer face of flanged nut **73** and extends towards the valve seat. Ball valve **97** is threaded onto the end of bolt **95** in a position such that when the diaphragm **62** is extended into the inlet valve chamber **90** by a hydraulic pulse in the hydraulic chamber **64**, the ball valve **97** will be held securely against the valve seat **92**. As shown the hydraulic valve chambers **64** are separate. However, in an alternative embodiment, the two chambers can be joined as one without any loss in effectiveness.

The hydraulic line **10** can be attached to any hydraulic pulsing means which will provide periodic hydraulic pulses of a definite volume. Preferably, however, the pulsing means is a piston-operated hydraulic pump such as that described in U.S. Patent No. 2,869,467, particularly FIGURE 8 thereof. The pulsing means will preferably have adjusting means which will set the volume of the hydraulic pulse transmitted to the hydraulic chamber of the pump and the valves so as to regulate the volume of material swept by the diaphragm **20** of the pump.

In the particular embodiment shown in FIGURE 1, the spring **29** of the pump has the greatest effective strength, equal to approximately 30 p.s.i. pressure drop across the diaphragm, for example. The spring **63** of the outlet valve has the next highest effective strength, equal to, for example, about 25 p.s.i. pressure drop across the diaphragm **61**, and the spring **89** of the inlet valve has the lowest effective strength, equal to about 20 p.s.i. pressure drop across the diaphragm **62**. The effective strength of spring **42** in check valve **35** is greater than the difference between the effective strengths of the spring **29** and spring **89**, approximately 12 p.s.i., in this example. The exact strength of each bias means is not critical, as long as the relationship between them remains the same.

In operation, the hydraulic pulsing means is adjusted to periodically supply a predetermined volume of hydraulic

fluid, in this case oil, through the line **10** and line **15** to the hydraulic chamber **12** and to the outlet and inlet valve hydraulic chambers **64** through lines **68** and **69** respectively.

When a positive hydraulic pulse is exerted by the pulsing means, fluid flows through line **10** and through line **15** into the hydraulic chamber and through lines **68** into the valve hydraulic chambers **64**. As the pressure begins to increase in each of the hydraulic chambers, the first bias means is overcome, the inlet valve bias means **89**, and the inlet valve diaphragm **62** is pushed outwardly into the inlet valve chamber **90** forcing ball valve **97** to seat firmly against valve seat **92**. This closes the inlet to the pump and prevents fluid from passing into or out of the pump chamber **5** through line **7**. As the pressure increases in the hydraulic system of the pump, the next bias means is overcome, spring **63** of the outlet valve, and diaphragm **51** is forced outwardly into the outlet valve chamber **55** unseating ball valve **81** from valve seat **58** and opening the outlet from the pump so as to permit fluid flow from the pump chamber **5** through the outlet line **9**. Finally, the pump bias means **29** is overcome and the diaphragm **53** flexed outwardly into the pumping chamber **5** and fluid is pushed out.

On the negative stroke of the hydraulic pulsing means, when the hydraulic pressure is being reduced, fluid flows outwardly from the hydraulic chambers through line **10**, leaving the valve hydraulic chambers **64** and pump hydraulic chamber **12** through lines **68**, **69** and **14**, respectively. Fluid cannot flow outwardly from the hydraulic chamber **12** of the pump until the pressure difference across valve **35** is greater than the effective strength of spring **42**, i.e. in this case about 12 p.s.i. Accordingly, the pressure in the pump hydraulic chamber **12** is not reduced until the valve **35** is open. As the pressure is decreased in the hydraulic system, the first valve to be actuated is the outlet valve **81** which seats against valve seat **58** as soon as the hydraulic pressure drops below the effective strength of its bias member **63**. As the pressure continues to drop, the hydraulic pressure against the inlet valve diaphragm **63** is relaxed until it is less than the effective strength of spring **89**. The bias spring then moves the valve **97** away from seat **92**, opening the inlet valve. When the pressure drop across valve **35** is greater than 12 p.s.i., the valve opens permitting fluid to leave the hydraulic chamber **12**. When the hydraulic pressure acting against diaphragm **20** is less than the effective strength of the bias means **29**, the diaphragm **20** moves back to its first position, drawing in pump fluid through inlet line **7**. The perforated plate **30** acts as a stop to prevent further movement of the diaphragm beyond the limiting position, if necessary.

As the diaphragm **20** moves back from its flex position, upon reduction of pressure in the hydraulic chamber **12**, fluid enters the pumping chamber **5** until the fluid in the chamber equals the volume of the chamber.

By adjustment of the volume of fluid delivered to line **10** and of the pulsing period of the hydraulic pulsing means, it will be apparent that any desired volume of fluid from the pumping chamber can be assured.

The inlet and outlet valves of FIGURE 1 can be readily replaced by other types of hydraulically actuated valves. One of the valves can be actuated by the fluid flow through the pump. Examples of various types of valves are set forth in U.S. application Ser. No. 396,794, filed Sept. 4, 1964 now U.S. Patent No. 3,256,825 issued on June 21, 1966.

FIGURE 2 shows the portion of the pump of FIGURE 1 outlined by the broken line wherein the two parallel hydraulic conduits **14** and **15** are replaced by the single conduit **16** containing check valve **100**. Check valve **100** comprises ball valve **102** which can move between stops **103** and the sliding annular orifice member **104**. The sliding annular orifice member permits flow through its central opening but will not permit flow around its outer edges when it is pushed up against valve seat **105** by the compression spring **107**. The remaining portion of the pump can be identical to that shown for FIGURE 1.

In operation, when the hydraulic pulse pressure is increasing, the ball **102** is pushed forward against stop **103** permitting flow to pass through line **16**. On the reverse stroke of the hydraulic pulse when the hydraulic fluid is flowing out of the pump chamber the ball is pushed against sliding orifice plate **104** plugging the orifice and preventing flow therethrough. As the pressure drop across the valve increases to a point sufficient to overcome the effective strength of the compression spring **107**, the annular plate **104** slides backwardly along the line **16** away from valve seat **105** permitting flow to pass through line **16**. Accordingly, the same result is obtained with the single passage as was obtained by the pair of parallel conduits of FIGURE 1 with check valves **35** and **37**.

When the present invention is utilized with diaphragm pumps having more than one diaphragm, and more than one pressure chamber such as the pump set forth in U.S. Patent No. 3,100,451, the check valve of this invention can be installed upstream of both hydraulic pressure chambers. In this case, one set of check valves will be located between both hydraulic pressure chambers and the hydraulic pulsing means. Alternatively, two sets of check valves can be used, one in the hydraulic connection to each hydraulic pressure chamber.

Similarly, several different pumps can be operated by a single hydraulic system. Each pump can have a separate diaphragm and a separate hydraulic pressure chamber attached to the same source of hydraulic pressure, or alternatively, several different diaphragms, one for each of several different pumping chambers, can form the walls of the same pressure chamber. The regulating means in either of such pumps can be located in the conduit immediately downstream of the pressure source, or where different pressure chambers are involved regulating means can be installed immediately upstearm of some or all of the pressure chambers.

Having regard to the foregoing disclosure, the following is claimed as the inventive and patentable embodiments thereof.

1. A pump for supplying fluid through a line comprising, in combination, a pump chamber; a pressure chamber; and a diaphragm therebetween normally biased towards a first position; a fluid connection through the pump chamber for flow of fluid to and from the chamber; a fluid pressure-responsive valve having open and closed positions and disposed across the line of fluid flow through the pump chamber for controlling the flow of fluid therein; said valve being normally biased towards one of the open and closed positions; a first hydraulic fluid line for connecting a source of hydraulic pressure and said pressure chamber for communication of source pressure to said pressure chamber for movement of said diaphragm away from said first position to pump fluid through said pump chamber and said fluid connection therethrough; valve means positioned in said first hydraulic fluid line such that flow of fluid to and from said pressure chamber proceeds via said valve means; a second hydraulic fluid line bypassing said valve means for connecting said source of hydraulic pressure and said fluid pressure responsive valve for communication of source pressure to said fluid pressure responsive valve for source pressure responsive movement of said fluid pressure repsonsive valve between its respective positions; the fluid pressure responsive valve and the diaphragm being moved in a pre-determined sequence by pre-determined hydraulic pressure developed by said source in said second hydraulic fluid line and in said pressure chamber, respectively; said valve means permitting free flow of fluid into said pressure chamber but permitting flow of fluid out of said pressure chamber only upon a pre-determined pressure differential across said valve means, producing on alternate strokes of the pump a pressure difference between the pressure chamber and

the second hydraulic fluid line greater than the difference between the effective bias strength acting on the valve and the effective bias strength acting on the diaphragm, thereby maintaining the sequence of movement of the valve and the diaphragm upon each successive stroke of the pump.

2. A diaphragm pump in accordance with claim 1 wherein the valve means comprises check valve means in the first hydraulic fluid line, bias means operatively connected to said check valve means in a manner permitting the valve to open to flow in one direction at a substantially zero pressure drop across the valve and permitting the valve to open to flow in the other direction only at a predetermined pressure drop across the valve, the effective strength of the bias means acting upon the check valve being greater than the difference between the effective bias strength on the diaphragm and the effective bias strength on the valve.

3. A pump in accordance with claim 1 wherein the fluid pressure responsive valve is disposed across the fluid inlet to the pumping chamber.

4. A pump in accordance with claim 1 wherein the fluid pressure responsive valve is disposed across the fluid outlet from the pumping chamber.

5. A pump in accordance with claim 4 wherein a second fluid pressure-responsive valve is disposed across the fluid inlet to the pump chamber for controlling the flow of fluid thereto, the valve having open and closed positions and being normally biased towards one of the open and closed positions, this valve also being connected to said source of hydraulic pressure for movement of said second fluid pressure responsive valve in response to source pressure.

6. A pump in accordance with claim 5 wherein the effective bias strength acting on the diaphragm is greater than the effective bias strength acting on the outlet valve which is in turn greater than the effective bias strength acting on the inlet valve and wherein the pressure difference between the pressure chamber and the second hydraulic fluid line is greater than the difference between the effective bias strength acting on the pump diaphragm and the effective bias strength acting on the inlet valve.

7. A pump in accordance with claim 5 wherein the effective bias strength acting on the diaphragm is greater than acting on either valve and wherein the pressure difference between the pressure chamber and the second hydraulic fluid line is greater than the difference between the effective bias strength acting on the pump diaphragm and the effective bias strength acting on the outlet valve.

8. A pump in accordance with claim 1 wherein the first hydraulic fluid line comprises two parallel fluid conduits, the conduits each having a check valve, one check valve preventing flow in a first direction, the second check valve preventing flow in the other direction, the first conduit having a check valve unbiased to open at substantially zero pressure in one direction and the other conduit having a check valve biased to prevent flow of fluid therethrough in the other direction until a predetermined pressure drop is produced across the check valve.

9. A pump in accordance with claim 1 wherein the first hydraulic fluid line comprises a single fluid conduit including a double-acting valve set to open in a first direction to fluid flow at substantially zero pressure drop and biased in the other direction, to prevent the valve from opening until a predetermined pressure drop is produced across the double-acting valve.

10. A pump in accordance with claim 1 wherein the pressure-responsive valve includes a diaphragm.

11. A pump in accordance with claim 1 wherein the pressure responsive valve includes a bellows.

12. A pump in accordance with claim 1 wherein the pressure-responsive valve and bias means are combined and comprise a resilient Belleville spring.

13. A pump in accordance with claim 1 wherein the pressure responsive valve includes a piston reciprocatingly mounted in a cylinder.

14. A pump for suppling fluid through a line comprising, in combination, a pump chamber, a pressure chamber and a diaphragm therebetween; first bias means operatively connected to the diaphragm and normally retaining the diaphragm in a first position; a first fluid connection through the pump chamber for flow of a fluid to and from the chamber; an inlet valve and valve seat and an outlet valve and valve seat disposed across the line of fluid flow through the pump chamber for controlling the flow of fluid therethrough, the inlet and outlet valves being mounted for to and fro movement between open and closed positions, respectively, away from and toward the valve seat; valve bias means operatively connected to each of said valves and normally retaining said valves in a first position, the inlet valve in an open position and the outlet valve in a closed position; fluid pressure-responsive means operatively connected to each of the valves; and a hydraulic system comprising hydraulic pulse means; a first hydraulic fluid connection between the pulse means and the pressure chamber for flow of pressure fluid to the pressure chamber for movement of the diaphragm away from the first position to pump fluid through the pump chamber; a second hydraulic fluid connection communicating the fluid pressure-responsive means with the pulse means for movement of the inlet and outlet valves away from their first position to their other position in response to fluid pressure in the hydraulic system, the valves and the diaphragm being moved in a predetermined sequence by predetermined hydraulic pressure developed by the pulse means in the second hydraulic fluid connection and in the pressure chamber, respectively; and regulating means in said first hydraulic fluid connection for maintaining the order of actuation of the valves and the diaphragm by hydraulic pressure during successive strokes of the pump comprising check valve means in the first hydraulic fluid connection, bias means operatively connected to said check valve means in a manner permitting the valve to open to flow in one direction at a substantially zero pressure drop across the valve and permitting the valve to open to flow in the other direction only at a predetermined pressure drop across the valve, the effective strength of the bias means acting upon the check valve being greater than the difference between the effective bias strength on the diaphragm and the effective bias strength on the valves.

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DONLEY J. STOCKING, *Primary Examiner.*

ROBERT A. O'LEARY, *Examiner.*

W. J. KRAUSS, *Assistant Examiner.*