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Peterson

[11] **3,908,373**

[45] **Sept. 30, 1975**

[54] **HIGH ENERGY RATE ACTUATOR**

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[22] Filed: **May 1, 1972**

[21] Appl. No.: **249,214**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 91,651, Nov. 23, 1970, abandoned.

[52] **U.S. Cl.** **60/371;** 91/50; 91/165; 91/300; 91/321; 92/134; 417/402

[51] **Int. Cl.**[2] **F01B 7/18;** F01L 25/04

[58] **Field of Search** 91/321, 300, 308, 309, 91/313, 276, 329, 165, 417, 392, 50; 92/134; 417/402; 60/371

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Primary Examiner—Paul E. Maslousky

[57] **ABSTRACT**

A high energy linear actuator includes an enclosed cylinder with a sleeve slideable within the cylinder to define a compression chamber and a liquid chamber on opposite sides of the sleeve. A piston ram extends slideably through the liquid end of the cylinder and the other internal end of the ram is slideable within the central bore in the sleeve to expose the inner end of the ram to the compression chamber. The actuator includes a special sealing arrangement and porting arrangements, which may be controlled by a variety of valve systems. The actuator is operated by pumping a pressurized liquid into the liquid chamber to urge the sleeve and piston in unison toward the opposite end of the cylinder and compressing the gas in the compression chamber. The seal between the sleeve and piston then is broken to relieve the advancing force of the pressurized liquid on the piston. The force of the compressed gas then acts immediately on the exposed inner end of the piston to drive the piston at high velocity and with substantial force.

23 Claims, 15 Drawing Figures

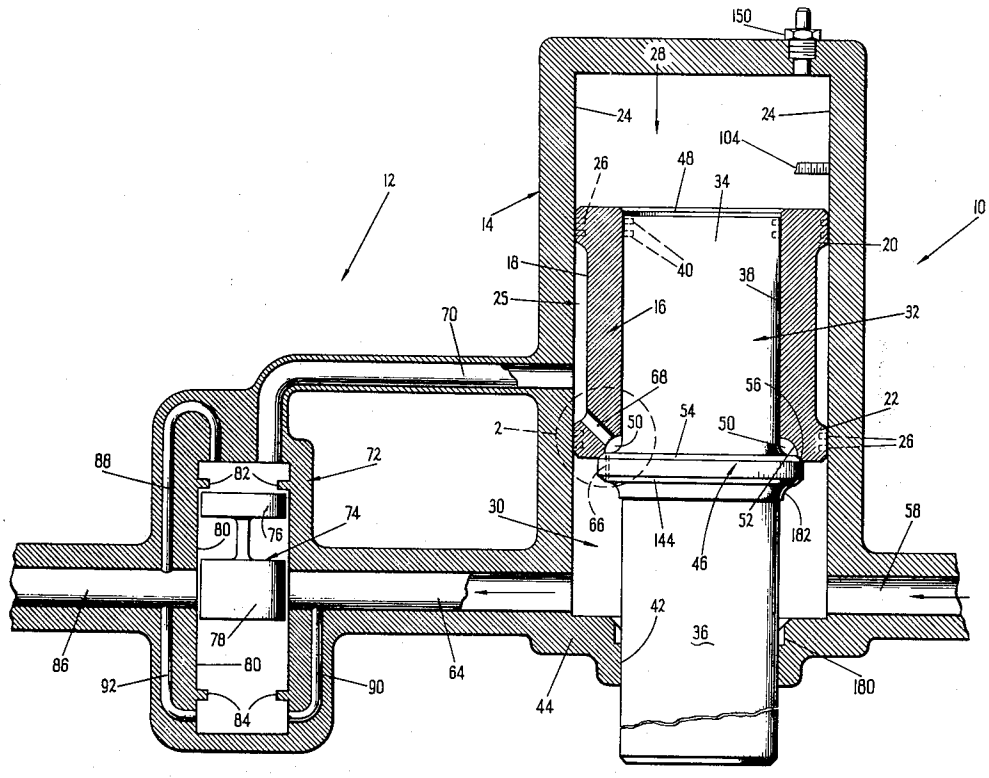


FIG. 1

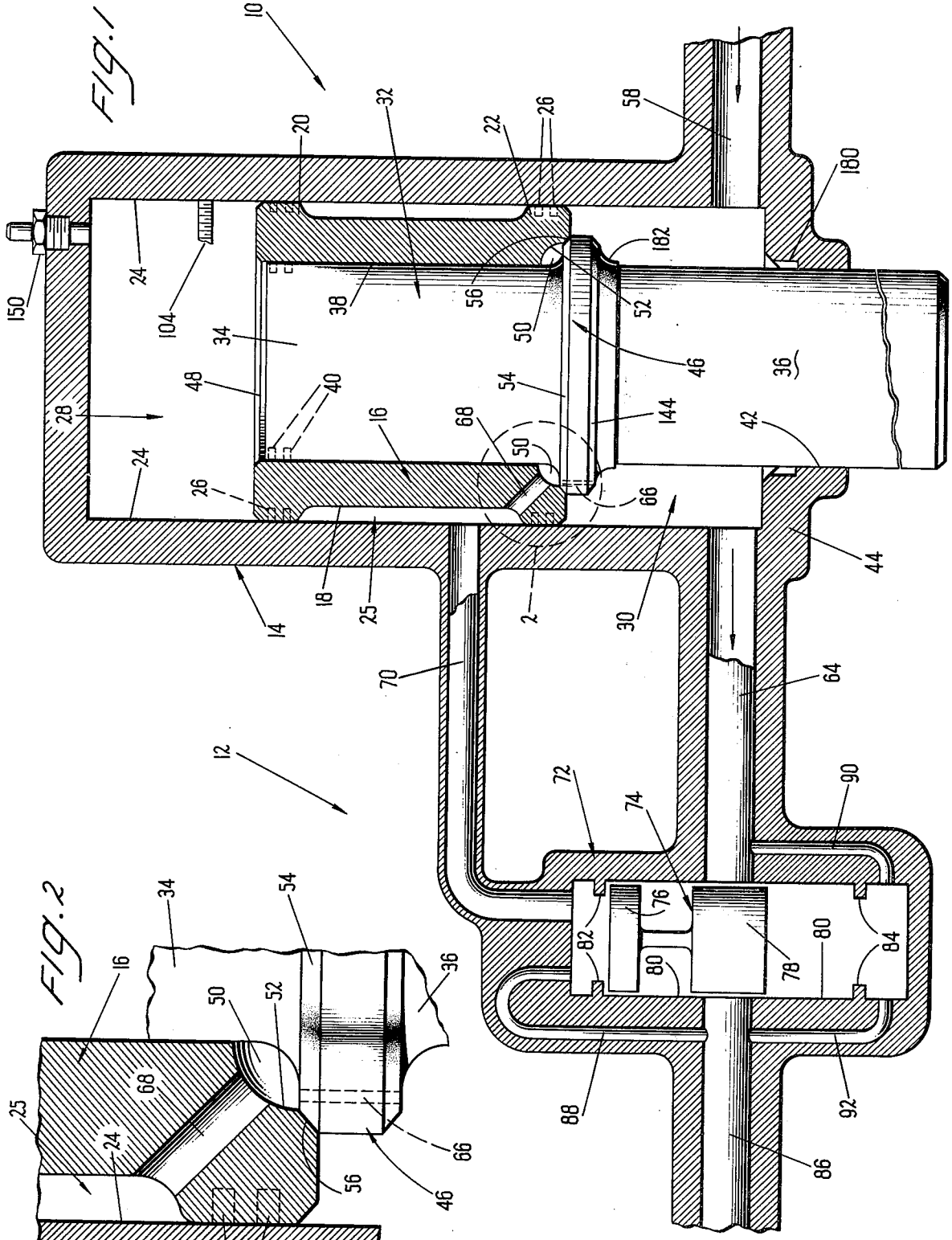


FIG. 2

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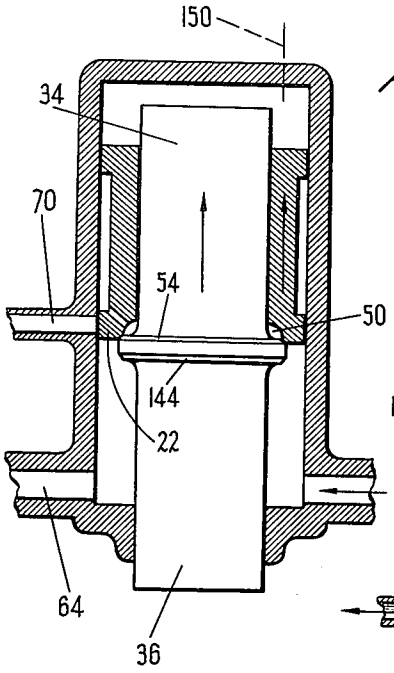


FIG. 3

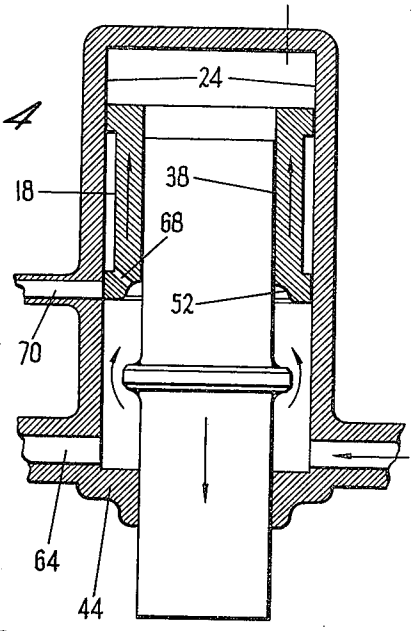


FIG. 4

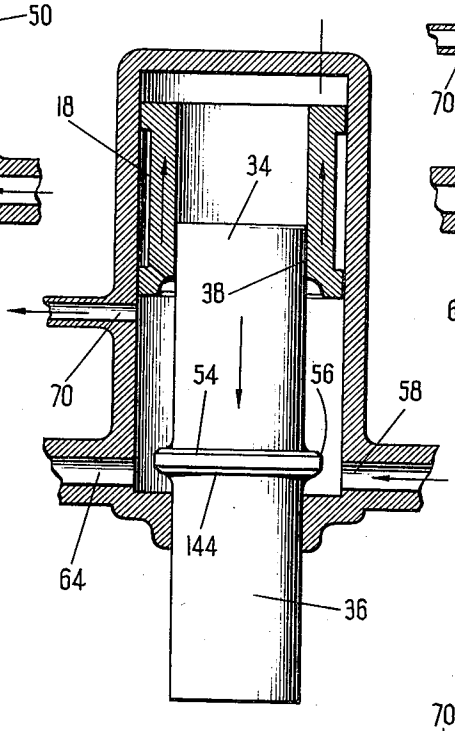


FIG. 5

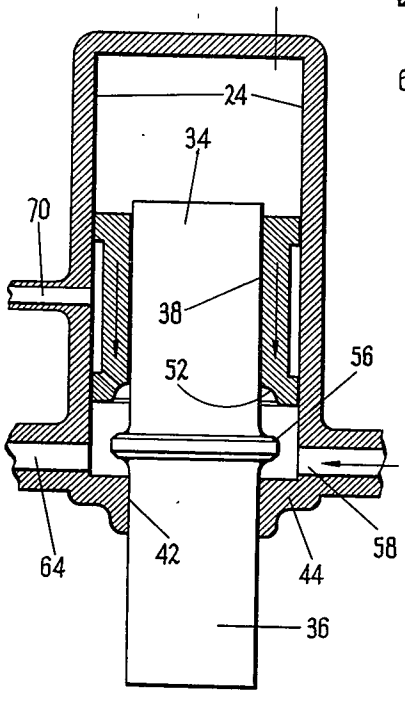


FIG. 6

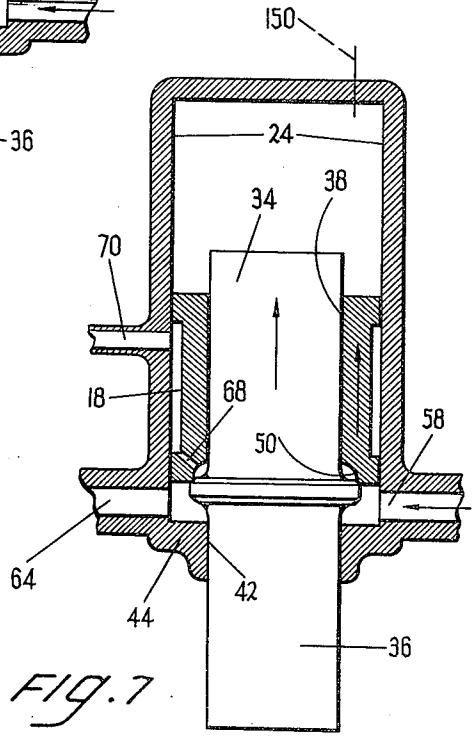


FIG. 7

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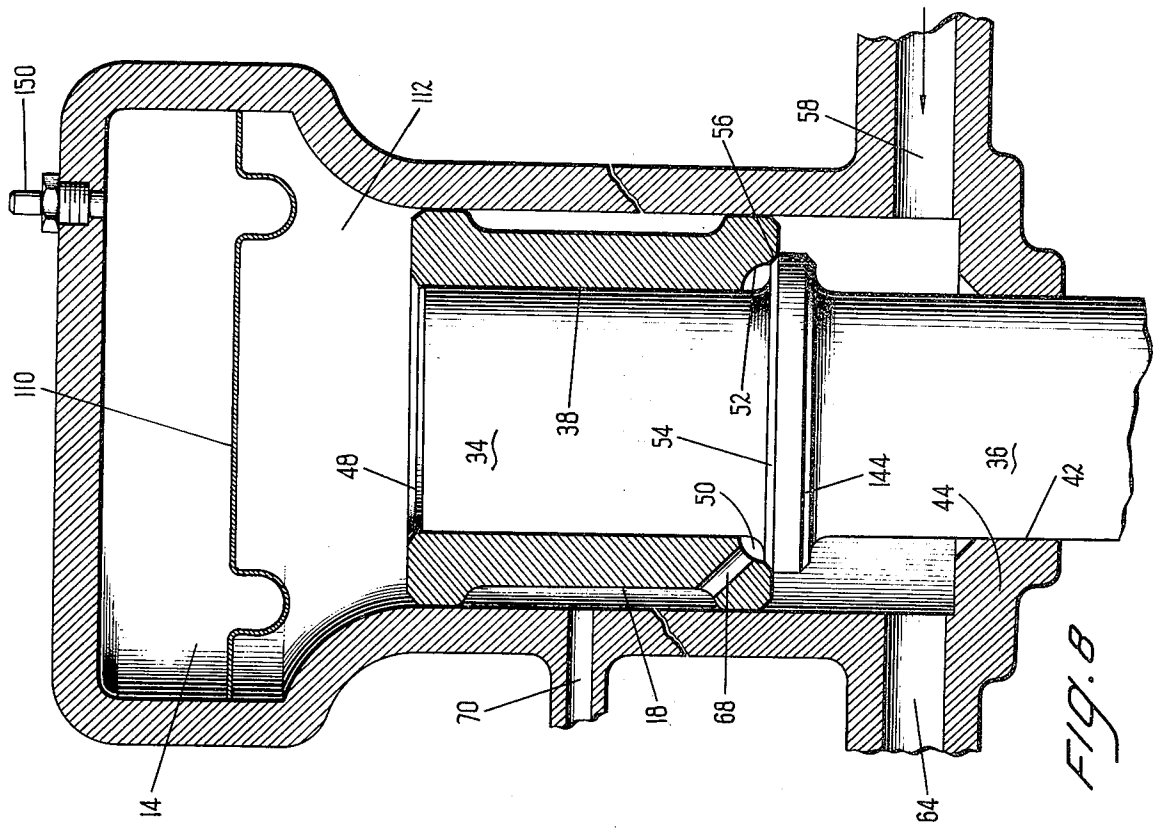


FIG. 8

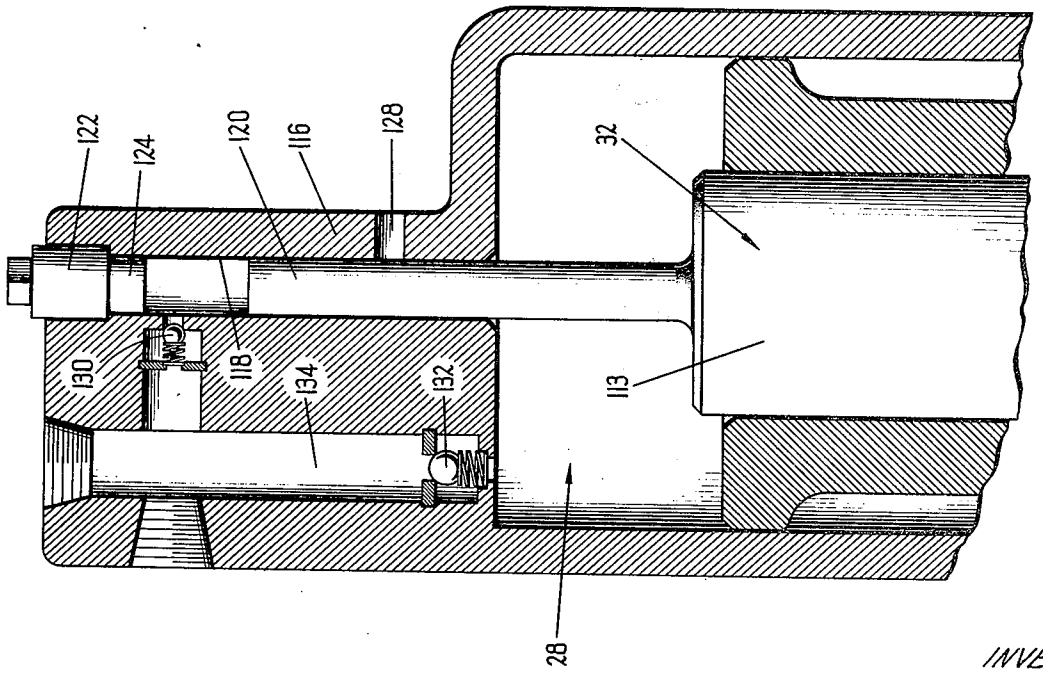


FIG. 9

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FIG. 12

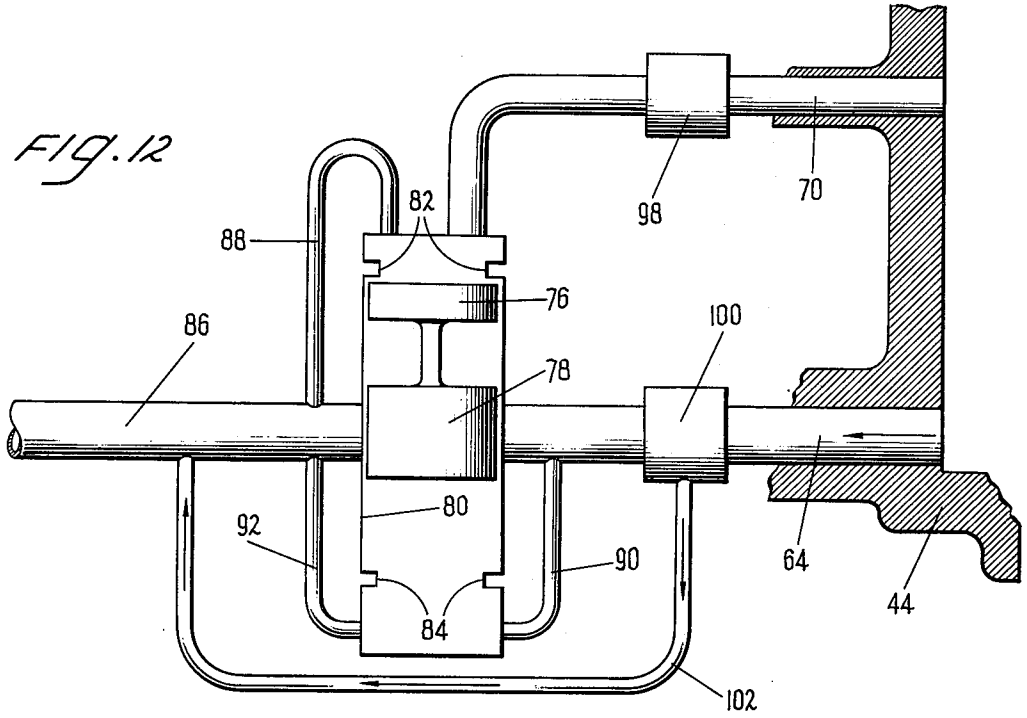
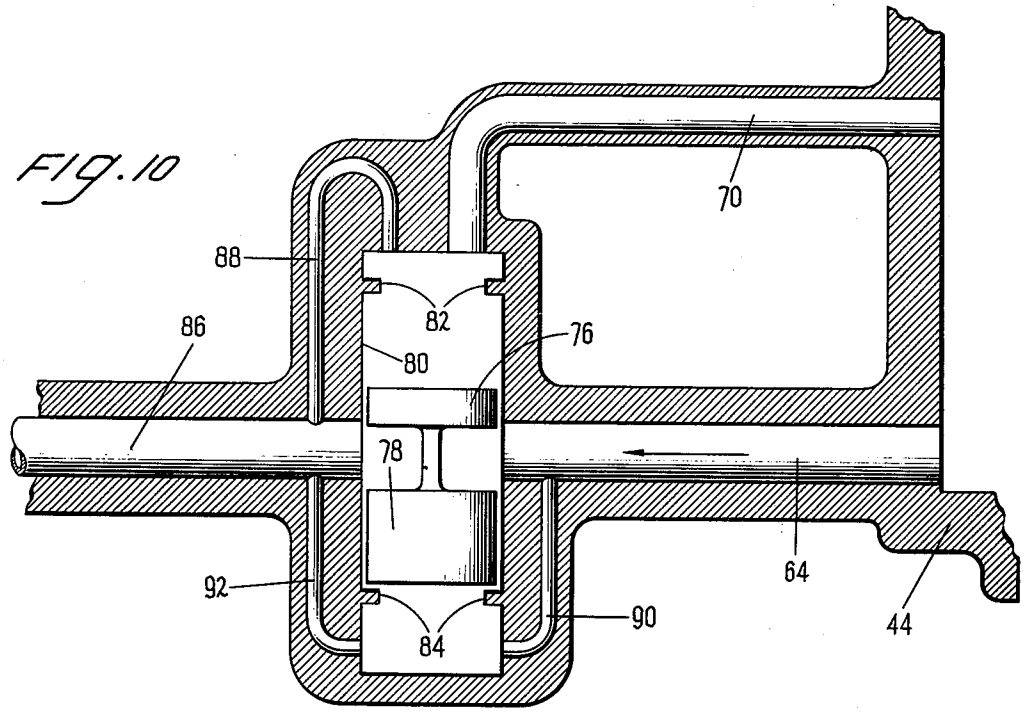


FIG. 10



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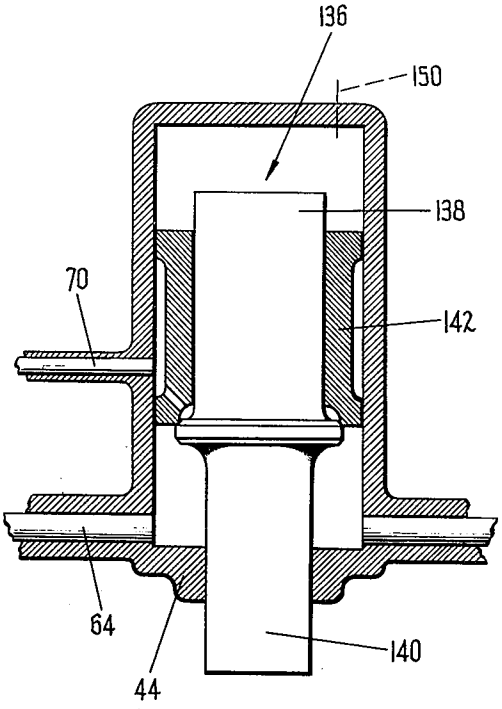


FIG. 14

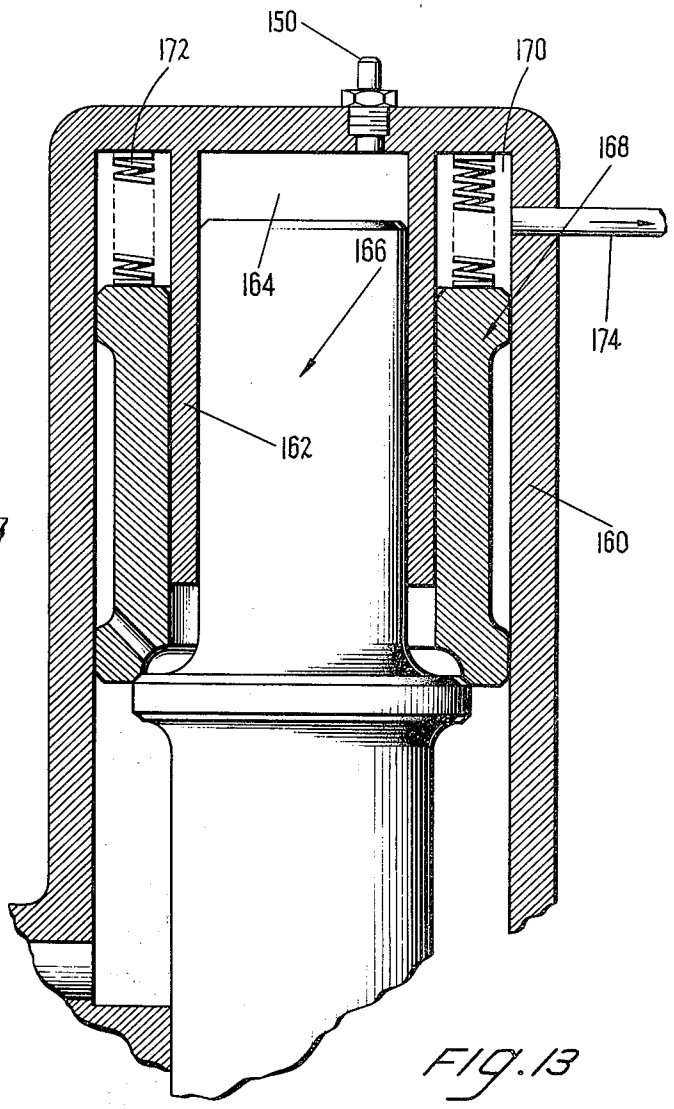


FIG. 13

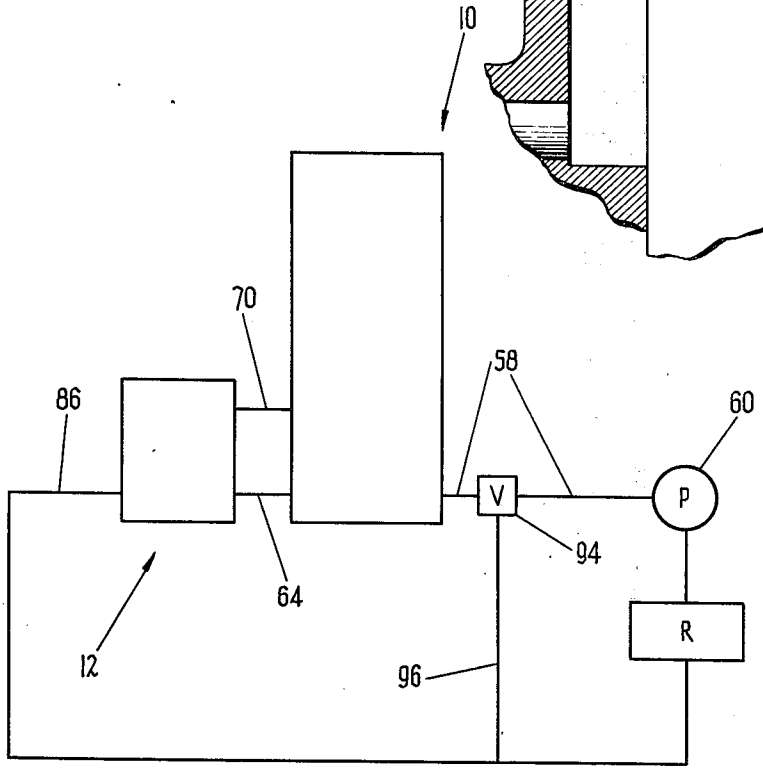
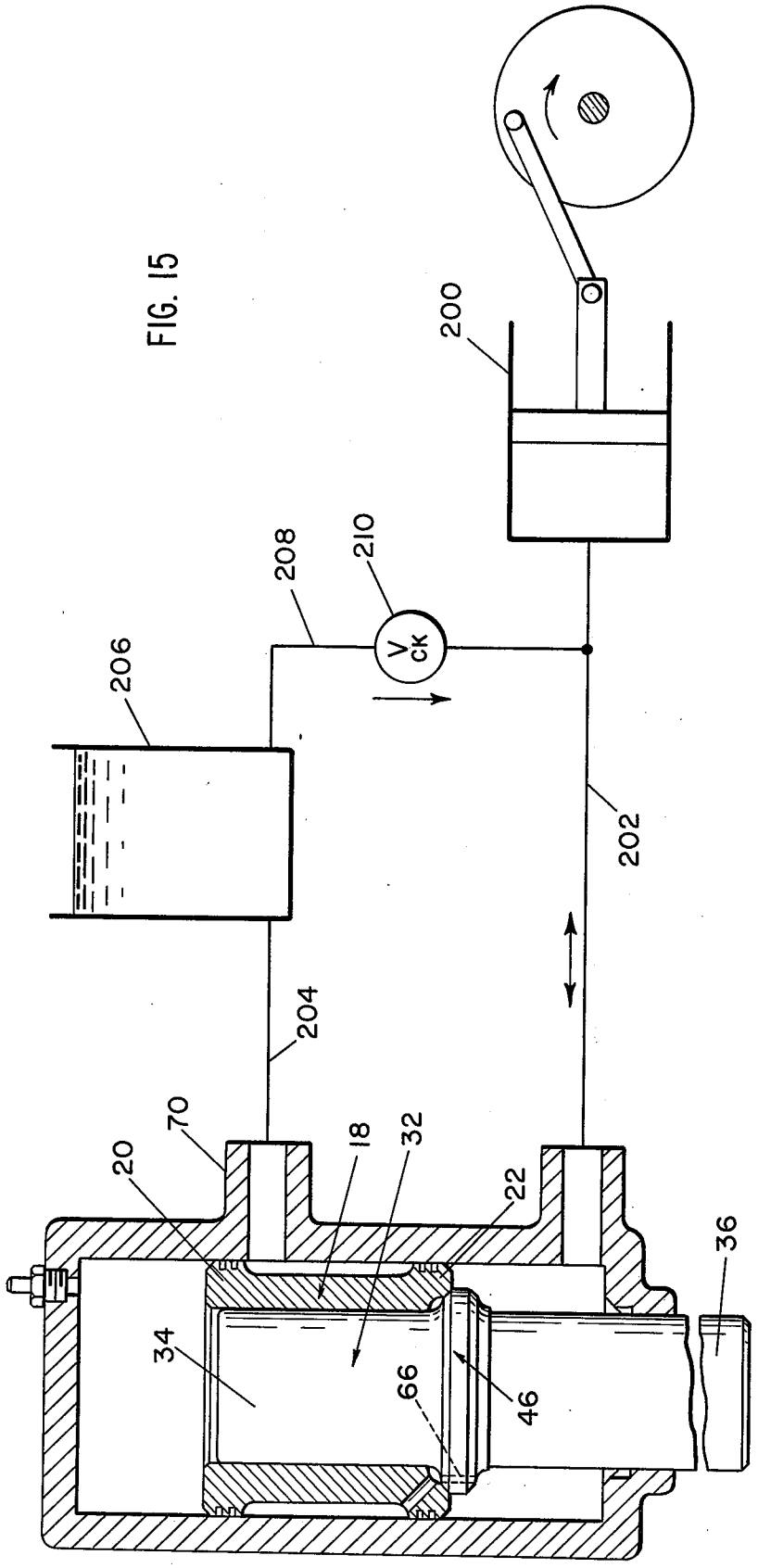


FIG. 11

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FIG. 15



HIGH ENERGY RATE ACTUATOR

This application is a continuation-in-part of my earlier application Ser. No. 91,651 filed Nov. 23, 1970, now abandoned.

BACKGROUND OF THE INVENTION

A variety of high energy rate actuators have been proposed and employed in the prior art for a variety of purposes. In general, they all are intended to impart a high velocity linear motion to a ram to develop a high energy impacting force. For example, high velocity linear actuators may be employed in rock drills, pavement breakers, punch pressers, forging hammers, nail drivers, and the like. The actuator may deliver a single impacting blow or a series of repetitive blows, depending on its construction and the device with which it is employed.

High velocity actuators are designed to store energy at modest power levels and to release the energy in a short time and at a high rate during the output stroke. Because the actuator elements characteristically function at widely different velocities during various portions of their cycles, they have not been entirely compatible with conventional constant flow hydraulic systems because such systems cannot operate properly when the fluid velocity varies over a wide range.

Additionally, it has been accepted generally that actuators of the type described which employ a compressible energy storage medium, such as a gas, are unacceptable in many applications because the compressibility of the gas and the relatively low pressure levels generally associated with the gas require that the parts of the actuator be of massive design and large capacity. Accordingly, actuators have been of complex design which is undesirable, particularly when the actuator is to be used for a heavy duty purpose such as impacting. It is among the primary objects of the invention to provide a rugged, extremely simple actuator having only two basic moving parts, which may employ a compressible medium as the energy storage medium and which nevertheless avoids the foregoing difficulties.

SUMMARY OF THE INVENTION

In brief, the invention is embodied in an actuator having a substantially enclosed cylinder and a specially formed sleeve slideable freely within the cylinder. The sleeve separates and defines a liquid chamber and a compression chamber at opposite ends of the cylinder. An elongated ram or piston has an outer end which extends slideably out of the liquid end of the cylinder, the inner end of the piston being slideable within a bore in the sleeve to expose the inner end of the piston to the compression chamber. A sealing collar is formed integrally with the piston and extends circumferentially about the piston between its ends. The sealing collar is larger in diameter than the sleeve bore and is engageable with a surface on the sleeve to form a breakable seal against the liquid end of the sleeve. In operation, liquid under pressure is pumped into the liquid chamber to urge the piston into sealing engagement with the sleeve and then urge the piston and sleeve in unison toward the compression end of the cylinder to compress the gas within the compression chamber. The pressurized liquid maintains the collar in sealing engagement with the piston throughout the compression stroke. At the end of the compression stroke, the pressure of the liquid tending to maintain the seal is relieved. The only remaining unbalanced force acting on the piston then is the force of the compressed gas in the compression chamber which is exposed to the inner end of the piston and drives the piston toward the liquid end of the actuator at a high velocity. It is important to note that as the piston advances in the power stroke; it does not displace any liquid through ports, lines, or ducts which would require a high liquid velocity. A variety of valving systems may be associated with the actuator to provide either for single blow actuation or automatic repetitive cycling.

The following description of the invention is illustrative in that it describes primarily the gaseous compressible energy storage means. It should be noted, however, that other forms of energy storage means may be employed such as a compression spring or the weight of the piston itself. The latter arrangement may be employed as in a pile driver.

It is among the primary objects of the invention to provide a high velocity linear actuator of very simple design, which avoids high liquid velocities.

Another object of the invention is to provide a compact actuator in which the energy storage medium comprises a compressible gas or other member, yet which is capable of delivering a substantial power output.

A further object of the invention is to provide a high velocity linear actuator which may be operated in association with constant flow hydraulic systems without excessive efficiency loss or pressure surges in the liquid system.

DESCRIPTION OF THE DRAWINGS

These and other objects and advantages will be understood more fully from the following detailed description thereof with reference to the accompanying drawings wherein:

FIG. 1 is a sectional elevation of the actuator in association with one of a number of possible valve control devices;

FIG. 2 is an enlarged illustration of the seal between the piston and the sleeve;

FIGS 3, 4, 5, 6, and 7 are somewhat diagrammatic illustrations of the actuator in various positions during a complete cycle;

FIG. 8 is an illustration of a modified form of the actuator;

FIG. 9 is an illustration of still another modification in which the actuator is also employed to power a compressor;

FIG. 10 is an illustration of the valve control device of FIG. 1 when in its shifted to open position;

FIG. 11 is a diagrammatic illustration of a complete fluid circuit embodying the invention;

FIG. 12 is an illustration of a modified valve arrangement;

FIG. 13 is an illustration of a modified actuator which reduces the likelihood of gas leakage from the compression chamber;

FIG. 14 shows a modified actuator in which the upper and lower portions of the piston are of different diameters; and

FIG. 15 is an illustration of a modified arrangement for controlling operation of the device in which an alternating pump is employed and which includes simplified valving means.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 shows the basic actuator assembly 10 connected to one of a number of possible control vaving arrangements, indicated generally by the reference character 12. The actuator assembly includes an enclosed cylinder 14 and a sleeve 16 which is slideable within and along the axis of the cylinder 14. The sleeve 16 is relieved circumferentially about its surface 18, except at its ends which define flanges 20, 22, which engage slideably the inner wall 24 of the cylinder 14 to guide the sleeve 16 for sealed movement along the cylinder. The relieved surface 18 and cylinder wall 24 define an annular volume 25. The seal between the periphery of the flanges 20, 22 and the cylinder wall 24 may be enhanced by piston rings or compliant seals, as suggested in phantom at 26 in FIG. 1. The slideable sleeve 16 cooperates with the cylinder 14 to define variable volumes at opposite ends of the cylinder 14. Thus, a gas compression chamber 28 is defined at one end of the cylinder 14 and a liquid chamber 30 is defined at the other end.

For ease of explanation, directions toward the gas chamber end of the actuator will be referred to as "upward" and directions toward the liquid chamber end of the actuator will be referred to as "downward". It should be understood, however, that the device may be operated in any attitude and is not restricted to operation in the position shown in the drawings.

The actuator 10 also includes a piston 32 which extends along the axis of the actuator having an upper end 34 and a lower end 36, the lower end 36 serving as the output ram. The upper end 34 of the piston 32 is slideably received within a central through bore 38 in the sleeve and, if desired, the seal may be enhanced by conventional piston rings or compliant seals, as suggested in phantom at 40 in FIG. 1. The lower output end 36 of the piston 32 projects downwardly through an opening 42 formed in the bottom wall 44 of the actuator. The piston 32 and sleeve 16 thus are slideable in relation to the cylinder 14 and also are slideable with respect to each other along the axis of the actuator. In this embodiment, the upper and lower ends 34, 36 of the piston 32 are equal in diameter.

The piston 32 also includes an integral enlarged circumferential collar 46 between the ends of the piston. The collar 46 preferably is located along the piston so that when it engages the bottom of the sleeve, as described below, the upper surface 48 of the piston 32 is at approximately the same level as the upper end of the sleeve and exposured to the gas compression chamber 28. The periphery of the collar 46 is spaced substantially from the internal cylinder surface 24. When the sleeve and piston are in the position shown in FIG. 1, the collar 46 serves to define, in part, the annular void 50. The annular void 50 is completed by the formation of an annular undercut surface 52 at the lower, internal region of the sleeve. When the sleeve and piston are together, as shown in FIG. 1, the annular void 50 is sealed by mating of a sealing surface 54 on the collar 46 with a complimentary annular seat 56 formed at the bottom of the sleeve. In the preferred embodiment shown, the sealing surface 54 and seat 56 mate in a chamfered configuration but other contours may be provided as desired.

The foregoing three elements, the cylinder, the sleeve and the piston comprise the only moving primary parts of the actuator assembly. In brief, and as described in detail below, the actuator is operated by pumping a pressurized liquid into the liquid chamber 30 while maintaining the annular void 50 at a lower pressure to cause the piston and sleeve to rise in sealed unison in the compression stroke. This compresses gas entrapped in the compression chamber 28. At the end of the compression stroke the pressure in the annular void 50 is equalized with that in the liquid chamber 30, thus releasing the seal between the collar 46 and the seat 56. Because the only unbalanced force then acting on the device is the pressure of the gas in the compression chamber 28 on the upper surface 48 of the piston 32, the piston is urged downwardly at a high velocity in a power stroke, without displacing liquid from the chamber 30.

Operation of the actuator in the foregoing manner will be understood more fully with reference to FIGS. 10 and 2 through 7 in conjunction with the valve control arrangement of FIG. 1. At the beginning of the cycle, the valving arrangement 12 is in the position shown in FIG. 1, to effectively close the liquid chamber 30. Liquid is introduced into the liquid chamber through an inlet 58 which is connected to an appropriate pump 60 and liquid supply (See FIG. 11). The pump 60 may be of the continuously operating positive displacement type as a gear pump. An outlet port 64 which also is in communication with the liquid chamber 30 and leads to the valving arrangement 12 is maintained in a closed position by the valving arrangement at this time. As the liquid is pumped into the effectively closed liquid chamber 30, the piston 32 and sleeve 16 are raised in unison toward the position shown in FIG. 3 to compress the gas entrapped in the chamber 28. During this compression stroke, the collar 46 is in firm sealing engagement with the seat 56 of the sleeve 16 to maintain the pressure differential between the annular void 50 and the liquid chamber 30. A small bleed passage 66 is formed through the collar 46 to permit a limited flow of pressurized liquid from the liquid chamber 30 into the annular void 50. The annular void 50, in turn, is in communication with the annular volume 25 by means of a passage 68 formed through the sleeve. The annular volume 25 is in communication with a vent or control port 70 which, in turn, is connected to the valving arrangement 12 in a manner later described. The bleed passage 66 is considerably smaller than the bleed passages 88, 90, 92 (described herein), so that during the compression stroke, when pressurized liquid is pumped into the liquid chamber 30, flow through the bleed passage 66 into the annular void 50 will be relatively slow so as not to equalize the pressure across the collar and destroy the seal.

During the compression stroke, the control port 70 is unblocked and in communication with liquid under a lower pressure which permits continuous liquid flow through the bleed passage 66 without any pressure build up. At the completion of the compression stroke, as shown in FIG. 3, the lower flange 22 of the sleeve 16 blocks the control port 70 to preclude further flow through the passages 66, 50, 68, and 25, to permit liquid pressure in the annular void 50 to build up to equalize that in the liquid chamber 30. Once the pressure across the collar 46 has been equalized, the only remaining unbalanced force acting on the piston 32 is

that of the compressed gas in the compression chamber **28**, which immediately drives the piston **32** downwardly in a power stroke as shown in FIG. **4**. It should be noted that during the power stroke, the liquid in the chamber **30** presents little resistance to the piston because the periphery of the collar **46** is spaced substantially from the inner surface of the cylinder wall **24**. This substantial clearance provides amply for fluid flow about the collar **46** in the manner suggested by the arrows in FIG. **4**, and there is no net displacement of liquid from the chamber **30** during the power stroke.

When the actuator is not employed to deliver any useful impact, it is preferable to provide a snubber to cushion the impact of the piston against the lower end of the cylinder. As shown in FIG. **1**, this may comprise a counter bore **180** formed in the lower end of the cylinder, which receives a flange **182** formed on the piston below the collar. The flange diameter is less than the diameter of the counter bore **180** to permit liquid to be squeezed out from between these parts as they mate and provide a cushioning effect.

When the actuator is operated in association with a continuously operating, constant flow pump, the contiuned pumping of liquid into the chamber **30** during the power stroke causes the sleeve to continue its upward movement, thus uncovering the control port **70** as shown in FIG. **5**. The sleeve also rises because of the drop in pressure in the compression chamber as the piston is driven downwardly.

As described below in detail, the control port **70** is connected to the valving arrangement **12** so that when the control port **70** is reopened, flow through the port **70** will trigger the valving arrangement **12** to open the discharge port **64** and permit the chamber **30** to be exhausted. This, in turn, permits the sleeve **16** to move downwardly as shown in FIG. **6** toward the position shown in FIG. **7** at which time the discharge port **64** may again be closed in readiness for another operating cycle. Inlet flow is not stopped at any time in this cycle.

The valving arrangement **12** shown in FIGS. **1** and **10** is designed to provide fully automatic repetitive cycling of the actuator. The valving arrangement **12** includes a valve body **72** which is illustrated somewhat diagrammatically. A spool valve **74** having a first pilot spool **76** and a second primary spool **78** is slideably contained within a bore **80** formed in the valve body **72**. The extreme alternate positions of the spool **74** within the bore **80** are limited by flanges **82, 84** which project radially inwardly into the bore to engage the first and second spools **76, 78** respectively. The outlet port **64** from the liquid chamber **30** of the actuator is connected to the primary end of the bore **80** and a return conduit **86** is in communication with the primary end of the bore. The spool valve **74** and the stops **82, 84** are arranged so that the outlet port **64** is either blocked by the second spool **78** or is unblocked and in communication with the return conduit **86** as shwon in FIG. **10**. The control port **70** is in communication with the first end of the bore **80** so that any pressure developed in the port **70** will be applied to the pilot spool **76**. A relatively narrow bleed line **88** is connected between the first end of the bore **80** and return conduit **86**. A bleed line **90** is connected between the discharge port **64** and the second end of the bore **80**. Another bleed line **92** is connected between the second end of the bore **80** and the return conduit **86**. The return conduit **86** returns liquid to the liquid supply and, generally, is at a reduced pressure in relation to the liquid pressure in the other parts of the system. The bleed lines **88, 90** and **92** are considerably smaller than the control port **70** but are large as compared to the bleed passage **66** in the piston collar **46**.

Operation of the foregoing valving arrangement in conjunction with the operative cycle of the actuator is as follows. When the actuator is beginning its cycle of operation from the position shown in FIG. **1**, the spool valve **74** is in the blocking configuration shown to close the discharge conduit **64**. The spool valve is maintained in this first, closed position, because the pressure acting on the pilot spool **76** is about equal to the return line pressure **86** and is less than the pressure acting on the primary spool **78**, which is at a high level because the second end of the bore is in communication with both the outlet port **64** and return line **86** through the bleed lines **90, 92**. It should be noted that the pressure acting on the end of the primary spool **78** is at an intermediate pressure between that of the bleed lines **90, 92**. There is no significant pressure developed within the control port **70** as a result of very small liquid flow through the bleed passage **66** in the collar **46**.

The pumped liquid urges the sleeve **16** and piston **32** upwardly in unison and in a compression stroke until the lower flange **22** on the sleeve **16** blocks the control port **70**. The spool valve remains in the closed configuration and the seal between the collar **46** and seat **56** on the sleeve **16** is broken, thus initiating the power stroke as described above.

The continuous operation of the liquid pump continues to raise the sleeve **16** beyond the control port **70** while the piston **32** is advancing downwardly in the power stroke. This uncovers the control port **70** as shown in FIG. **5** and exposes the port **70** to the high pressure of the pumped liquid beneath the sleeve **16**. The increased pressure in the control port **70** is communicated to the face of the pilot spool **76** which overcomes the intermediate pressure acting on the face of the primary spool **78**, thus driving the spool valve **74** to the open position shown in FIG. **10**. With the outlet conduit **64** in communication with the return line, the pressure within the liquid chamber **30** drops rapidly to a level below that within the gas compression chamber **28** which drives the sleeve **16** downwardly toward the collar **46** on the piston **32** as shown in FIG. **6**. During the descent of the sleeve **16** the pressure communicated between the chamber **30** and the control port **70** through the passage **68** maintains the spool valve **74** in the open configuration. If desired the rate of sleeve descent may be controlled by providng an appropriate restriction in the discharge conduit **64** between the bleed lines **90, 92** so as to maintain an intermediate pressure acting on the end of the primary spool **78**. This restriction may be formed by selecting a reduced space between the spools of the spool valve **74**.

When the descending sleeve seats against the collar **46** of the piston **32**, the control port **70** is effectively cut off from the pressure in the liquid chamber **30**. This drops the pressure in the control port **70** and the pressure acting on the pilot spool **76** to the reduced return line pressure while the higher, intermediate pressure acts on the second spool **78** to return the spool valve **74** to the closed configuration shown in FIG. **1**. The device then is in readiness for the next cycle.

With the foregoing, continuously operative valving arrangement **12**, proper valve closing requires a delib-

erate pressure drop in the open discharge conduit **64.** This, however, is desirable in order to avoid excessive descent velocity of the sleeve **16.**

The unit may be turned off and on by an appropriate three-way valve **94,** connected as suggested in FIG. **11** at the inlet line. The valve is arranged to shunt liquid flow directly to the return conduit, as through the shunt conduit **96,** when in an off position. Additionally, the inlet is never closed, so that liquid flow may always act against the piston and/or the sleeve.

The foregoing valve arrangement **12** may be modified to enable the number of repetitive blows to be controlled either as a single blow or as a short burst of blows. As shown in FIG. **12,** the valving arrangement is modified to include a normally open, manually operable trigger valve **98** in the control port line **70.** A pressure relief valve **100** is in communication with the chamber **30,** as by interposing the valve **100** along the outlet conduit **64.** The pressure relief valve is set at a level to by-pass flow before the lower flange **22** of sleeve **16** has moved upwardly into a blocking position over the control port **70.** Thus, during the compression stroke, the pressure relief valve **100** will open to terminate the compression stroke by precluding further pressure build up within the liquid chamber **30.** The liquid flowing through the pressure relief valve may be directed through the line **102** to the return line **86.** The piston and sleeve are held upwardly in a cocked position with the seal intact because the pressure within the chamber **30** remains greater than within the annular void **50.**

The device is actuated by closing the trigger valve **98** to permit the pressure across the collar **46** to become equalized as described above, which causes the piston **32** to descend and deliver a single blow. As long as the trigger valve **98** is held closed, valve **12** will not be activated and the sleeve **16** cannot descend. Continued inflow through inlet **58** will cause the sleeve **16** to rise further until it is mechanically prevented from further upward motion. Pressure will then build up in chamber **30** to the level permitted by the relief valve. Release of trigger **98** will open line **70** to shift valve **74.** With the spool valve in the open position, the pressure within the liquid chamber **30** drops and the sleeve **16** is urged downwardly under the force of the remaining compressed gas in the chamber **28.** As the flange **22** of the sleeve descends downwardly into sealing engagement with the collar **46** on the piston **32,** the seal causes the pressure in the control port **70** to drop below that of the intermediate pressure applied to the second spool **78.** This returns the spool valve **74** to the closed configuration of FIG. **1.** With the discharge line **64** blocked, continued operation of the pump **60** will raise the sealed sleeve and piston to the initial cocked position determined by the setting of the pressure relief valve **100** in which the flange **22** of the sleeve is just below the control port **70.** Once returned to this cocked position, the device is ready for another single blow when the trigger valve is activated.

FIG. **8** shows another embodiment of the invention which is adapted to minimize the possibility of any gas leading from the compression chamber **28** past the wall **24** and glanges **20, 22** or past the wall **38** and piston **32.** In this embodiment, a flexible membrane or diaphragm **110** is located at the upper end of the cylinder and defines an upper liquid chamber **112** and the upper gas compression chamber **114.**

FIG. **15** shows, diagrammatically, an alternate control arrangement for operating the actuator having a fluid pump **200** which alternately pumps fluid to and from the lower chamber **30** of the actuator instead of the constant flow pump previously described. For this purpose, the outlet of the pump **200** is connected by a line **202** to the pressure chamber **30** of the actuator. In this arrangement, the line **202** is the only connection to the chamber **30.** There is no need for the separate discharge line **64** described in the previous embodiment because the fluid from the chamber is discharged in a reversed direction through the line **202** back to the pump **200** as the pump reciprocates. Control port **70** is communicated to a source of low pressure by the line **204** which is connected to a fluid reservoir **206.** The reservoir **206** may be maintained at atmospheric pressure or at a slightly increased pressure but is at a pressure lower than that generated by the pump **200** during the compression stroke. The reservoir **206** also may be connected by the line **208** to the line **202** and may include a one-way valve **210** which permits liquid flow only in a direction from the reservoir to the line **202.** It should be noted that the line **204** is relatively small in relation to the line **202** so that it may function mainly as a bleed line. The cycling of the actuator member with this control arrangement is identical to that described previously. Operation of this control arrangement is as follows. With both the piston and sleeve in their lower position, the pump **200** is operated to pump fluid under pressure into the chamber **30** to raise in unison the piston and sleeve. During the inflow of fluid to the chamber **30,** a small quantity of liquid will bleed past the collar and through the control port **70** to the reservoir **206.** When the piston and sleeve have been raised so that the sleeve blocks the control port **70** the device is triggered in the same manner previously described. The pressure in the annular space builds up to that in the chamber to break the seal between the collar and the sleeve and enable the energy in the upper chamber to act on the upper end of the freed piston to drive it down. The sleeve is thereafter brought downwardly into sealing engagement with the collar by operation of the pump **200** in its alternate mode of pumping fluid out of the chamber **30** through the line **202.** During this stroke of the pump, a small quantity of fluid will be drawn from the reservoir through the valve **210** into the line **202** to make up that which bled toward the reservoir during the compression stroke.

FIG. **9** shows still another variation of the invention in which the reciprocating motion of the piston **32** is employed to power a self-contained compressor which feeds the gas chamber and maintains the gas in the chamber **28** at the necessary minimum level. The upper portion of the cylinder **116** is formed to define a vertical bore **118** which receives, slideably, the upper end of a piston extension **120** secured to and extending upwardly from the upper end of the piston **113.** The upper end of the bore is closed, as by a plug **122.** The plug **122** is threaded into the upper end of the cylinder block coaxially with the bore **118** and may include a projection **124** which fits closely and slideably against the bore **118,** to permit adjustment of the clearance volume remaining within the bore **118** when the piston extension **120** reaches the top of its stroke. An inlet port **128** is formed through the cylinder block and communicates the bore **118** with the atmosphere. As the piston **113** reciprocates along its axis, it develops a reduced

pressure within the bore **118** during the power stroke to ingest air through the inlet port **128** when the upper end of the piston extension **120** is at the bottom of its stroke. When the piston extension **120** moves upwardly, the entrapped air is compressed and is directed through the check valve **130.** The plug **122** is adjusted in relation to the check valve **130** so that the pressure within the bore **118** cannot exceed a maximum value.

The valve **130** is designed to open when this value is reached thus maintaining the passage **134** at this pressure level. The compressed gas in the passage **134** is admitted through the check valve **132** and into the chamber **28** only when the pressure within the chamber **28** falls below the pressure within the passage **134.** This would occur at the bottom of the actuator stroke and would be effective to permit flow through the valve **132** only when the pressure in the chamber **28** falls below the predetermined value. This maintains the pressure in the chamber **28** at a minimum predetermined value corresponding to the maximum pressure within the bore **18.** When starting the device, it may be necessary to cycle the actuator a few times until the desired pressure level has been reached. The variable clearance volume plug **122, 124** is adjustable to limit the peak pressure within the compressor which, in turn, and in cooperation with the check valves **130, 132,** becomes the minimum gas pressure in the gas chamber **28.**

In the foregoing description of the invention, the actuator has been described primarily as including a piston **32** in which the upper and lower ends **34, 36** are equal in diameter. FIG. **14** shows an actuator in which the piston **136** has an upper end **138** which is larger in diameter than the lower end **140.** In this configuration, when the piston **136** descends downwardly in the power stroke, the enlarged upper end **138** will cause the displacement of a volume of liquid. This, however, is accomodated by an upward acceleration of the sleeve **142.** In this manner, the sleeve may be employed to counteract piston inertial effects and to reduce the apparent recoil of the actuator. In any of the foregoing valving control arrangements, the frequency of the power strokes may be controlled by interposing adjustable throttling valves in any of the bleed lines **88, 90,** or **92.**

When the actuator is employed in heavy-duty, rugged environments, the piston impacting end **36** may become worn, and additionally, the piston and valve seat also may wear. Because of the simplicity and heavy-duty construction of the parts, they may be designed symmetrically so that when worn, they may be reversed to give essentially a double life. Thus, as shown in FIG. **1,** the underside of the collar **46** may be chamfered as at **144** for proper mating with the valve seat **56** when the piston is reversed. Additionally, the sleeve could be fabricated symmetrically to provide an annular void **50** at each end as well as a passage **68** through the sleeve at each end. During operation, however, the upper unused of the passage **68** should be closed as by a plug.

As shown in FIG. **1,** the actuator may be fitted with a gas recharging fitting **150,** in communication with the compression chamber **28** to maintain the desired minimum gas pressure in the chamber **28.**

FIG. **13** shows a modified version of the actuator which is intended to minimize gas leakage. This arrangement includes the cylinder **160** which has, at its upper end, a downwardly extending cup-like circular wall **162** which defines the compression chamber **164.** The upper end of the piston **166** is slideably received within the cup **162.** The sleeve **168** is slideable within the annular void **170** between the cylinder **160** and the outer surface of the cup **162.** The sleeve **168** is biased downwardly by a spring **172** which may be located within the void **170.** In this modification of the invention, the same valving and porting arrangements discussed above may be employed. The primary distinction of this modification of this invention is that there are fewer paths for possible leakage of compressed gas. Here the compressed gas within the chamber **164** is in communication only with the upper end of the piston **166** and there is only one possible leakage path, that between the piston **166** and the internal surface of the cup **162.** The springs **172** are employed to urge the sleeve **168** downwardly in the same manner as the compressed air in the upper chamber **28** in the embodiments previously described. Additionally, a vent **174** may be provided in communication with the annular void **170** so as not to entrap any gas within the void **170** and not to restrict movement of the sleeve **168.**

Thus, I have described an improved linear actuator of very simple design yet which is capable of producing a high impacting velocity. Moreover, the velocity is achieved by initially compressing a gas or other energy storage means and then applying the force of the stored energy to the piston without requiring rapid liquid displacement. The preferred embodiment is suited for use with a constant volume flow liquid pump. The actuator lends itself to a variety of control techniques and may be operated to provide fully automatic, continuous operation, semi-automatic operation or single blow operation.

It should be understood, however, that the foregoing description is intended merely to be illustrative of the invention and that other embodiments and modifications may be apparent to those skilled in the art without departing from its scope as defined in the appended claims. For example, the illustrative embodiment of the invention is related primarily to an arrangement in which the energy storage medium comprises a compressible gas retained within the upper chamber. This, however, could be replaced by a compression spring or other relatively compressible medium. Additionally, in some instances the invention simply may employ the mass of the piston itself as the energy storage medium. For example, when used as a pile driver in which the piston is relatively heavy the weight of the piston itself may be employed to effect the power stroke. In this configuration, however, the actuator must be vertically oriented with the upper end disposed above the lower end.

Having thus described the invention, what I desire to claim and secure by Letters Patent is:

1. A high energy linear actuator comprising:

a cylinder having first and second ends;

a member having first and second ends and being movable reciprocably within said cylinder and defining in cooperation with the cylinder a first chamber adjacent the first end of said cylinder;

a piston reciprocable along the axis of said cylinder and having a first end extending outwardly of the first end of said cylinder defining the first chamber and having a second end within a bore in said member for reciprocating movement both relative to and in unison with said member, said first end of said piston which extends outwardly of the first end

of the cylinder passing through the first chamber;

means connected to said cylinder for developing a pressure in said first chamber, said piston and said member having surfaces exposed in said first chamber and adapted to receive a component of said pressure in an axial direction away from said first chamber to move the piston and member in a compression stroke toward the second end of the cylinder,

a collar secured to said piston intermediate its ends and extending radially from and about said piston, said collar being exposed within said first chamber and having a sealing surface engageable with a seating surface formed on the first end of said member, said collar having a first surface facing said first chamber, said first surface comprising said surface adapted to receive a component of said pressure in an axial direction within said first chamber; and

means for maintaining the pressure on said sealing surface of said collar at a level which is lower than that acting on the first surface of said collar during said compression stroke, the pressure differential between the lower pressure on the sealing surface and the higher pressure on the first surface maintaining a seal between the piston and member causing unitary movement of the piston and member during the compression stroke;

energy storage means connected to said piston for storing energy developed by said unitary movement of said member and said piston and for exerting a component of force on said piston in an axial direction toward said first chamber; and

means for equalizing substantially all forces acting on said piston within said cylinder except for the force of said energy storage means whereby said stored energy may urge said piston at a high velocity toward said first end of said cylinder in a power stroke.

2. An actuator as defined in claim **1** wherein said means for equalizing said forces acting on said piston comprises:

means for equalaizing the magnitude of pressure acting on said sealing and first surfaces of said collar.

3. An actuator as defined in claim **1** wherein said means for maintaining said pressure differential on the surfaces of said collar comprises:

vent means for communicating at least a portion of the sealing surface of said collar to a source of lower pressure.

4. An actuator as defined in claim **3** wherein said vent means comprises:

means forming an undercut region at the first surface of said member inwardly of said sealing surface to define a void in cooperation with said sealing surface of said mated collar;

said member having a passage formed therethrough in communication with said void; and

means connecting said passage with said source of low pressure during said compression stroke.

5. An actuator as defined in claim **4** further comprising

means for precluding communication between said passage and said source of low pressure; and

means forming a bleed passage between said void and said first chamber to enable the pressure within said void to build up to that of said first chamber.

6. An actuator as defined in claim **5** wherein said bleed passage is formed through said collar.

7. An actuator as defined in claim **5** wherein said member comprises:

a sleeve slideably sealed at its ends to the internal surface of said cylinder, said sleeve having a reduced outer diameter at its midportion to define a sleeve chamer between said sleeve and the internal surface of said cylinder, said passage opening into said sleeve chamber;

said reduced outer diameter also defining first and second flanges on the sleeve at its first and second ends that slide on the internal surface of the cylinder,

said means communicating said source of low pressure with said passage including a port formed in said cylinder in communication with said sleeve chamber during said compression stroke, said port being connected to said low pressure source;

and wherein said means for precluding communication of said low pressure to said passage comprises:

means locating said port along said cylinder so that at the end of said compression stroke, the first flange of said sleeve will block said port and isolate said sleeve chamber from said low pressure source thereby to enable the pressure within said sleeve chamber passage and void to build up to that of said first chamber.

8. An actuator as defined in claim **7** wherein said means for developing a pressure in the first chamber for the compression stroke comprises a continuously operable fluid pump for pumping liquid under pressure to said first chamber, said actuator including control means further comprising:

pressure relief means in communication with the liquid in said first chamber and adapted to preclude build-up of liquid pressure above that level necessary to move the first flange of said sleeve to a position to block said port; and

manually operable valve means connected to said port to close said port and isolate the sleeve chamber from said pressure source.

9. An actuator as defined in claim **8** wherein said control means further comprises:

means for precluding closure of the discharge port from said first chamber to restrict the cycle of operation to a single blow, said means being manually resetable to permit closure of said discharge port.

10. An apparatus as defined in claim **7** further comprising control means for operating said actuator automatically and repetitively comprising:

fluid pump means connected to said first chamber and being constructed and arranged to alternatively pump fluid into said first chamber to increase the pressure therein and to pump fluid out of said chamber to relieve the pressure therein.

11. An apparatus as defined in claim **10** wherein said pump means is connected to said first chamber by a conduit, said apparatus further comprising:

means connecting a reservoir to said conduit; and

a one way valve interposed along said means connecting said reservoir to said conduit to permit liquid flow only in a direction from said reservoir to said conduit.

12. An actuator as defined in claim **5** wherein said energy storage means comprises;

means defining a second chamber at the second end of said member,

a compression spring disposed within said second chamber and engageable with the second end of said piston,

said spring storing energy in response to movement of said piston and member during said compression stroke.

13. An actuator as defined in claim **5** wherein said energy storage means comprises:

means defining a second chamber at the second end of said cylinder; and

a compressible gas filling said second chamber.

14. An actuator as defined in claim **13** further comprising:

reciprocating compressor means having an inlet in communication with the atmosphere and an outlet in communication with said second chamber; and

means connecting said reciprocating compressor means to said piston for movement therewith to maintain the gas within said second chamber at a minimum pressure level.

15. An actuator as defined in claim **14** wherein said compressor means comprises:

the second end of said piston having an extension slideably received within a compressor bore formed in the second end of said cylinder;

an inlet passage formed in the second end of said cylinder and extending between said compressor bore and having an end open to the atmosphere, the inner end of said inlet passage being positioned to be in communication with said compressor bore when said piston and extension are at the end of the stroke thereof toward the first chamber;

an outlet conduit connecting the end of said compressor bore and said compression chamber; and

check valve means in said outlet passage for precluding gas flow in a direction that is away from said second chamber.

16. An actuator as defined in claim **15** further comprising:

means for varying the volume of said compressor bore.

17. An actuator as defined in claim **13** wherein said energy storage means further comprises:

a flexible diaphragm mounted within said second chamber and defining first and second portions of said second chamber with the second end of the piston being exposed in the first portion, the second portion of said second chamber being filled with a liquid.

18. An actuator as defined in claim **13** further comprising control means for operating said actuator automatically and repetitively comprising:

means for relieving the pressure in said first chamber after said power stroke to a level below that of the gas within the second chamber to move the member downwardly toward the collar and to reseal said member to said collar; and

means for thereafter closing said pressure relieving means to enable said pressure to build up within said first chamber.

19. An actuator as defined in claim **18** wherein said means for applying said advancing force comprises:

a continuously operable fluid pump for pumping liquid under pressure into said first chamber;

said means for relieving said pressure within said first chamber comprising a discharge port; and

valve means for opening and closing said discharge port.

20. An actuator as defined in claim **19** wherein said means for maintaining said pressure differential across said collar from the sealing to first surfaces comprises vent means for communicating at least a portion of the sealing surface of said collar to a source of lower pressure and wherein said control means further comprises:

means for manually opening and closing said vent means.

21. An actuator as defined in claim **1** wherein both ends of said piston have the same cross-sectional dimensions.

22. An actuator as defined in claim **1** wherein said means for applying said advancing force comprises:

a continuously operable fluid pump for pumping liquid under pressure into said first chamber.

23. An apparatus as defined in claim **1** wherein said pressure relieving and pressure initiating means comprises:

a fluid pump means connected to said first chamber and being constructed and arranged to alternatively pump fluid into and out of said first chamber.

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