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Fisk et al.

[11] **3,796,050**
[45] **Mar. 12, 1974**

[54] HIGH ENERGY RATE ACTUATOR

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[73] Assignee: **Foster-Miller Associates**, Waltham, Mass.

[22] Filed: **May 18, 1972**

[21] Appl. No.: **254,482**

[52] **U.S. Cl.** **60/371**, 60/413, 92/134
[51] **Int. Cl.** **B30b 1/30**
[58] **Field of Search** 60/369, 371, 413; 91/47, 91/49, 422, 234; 92/134

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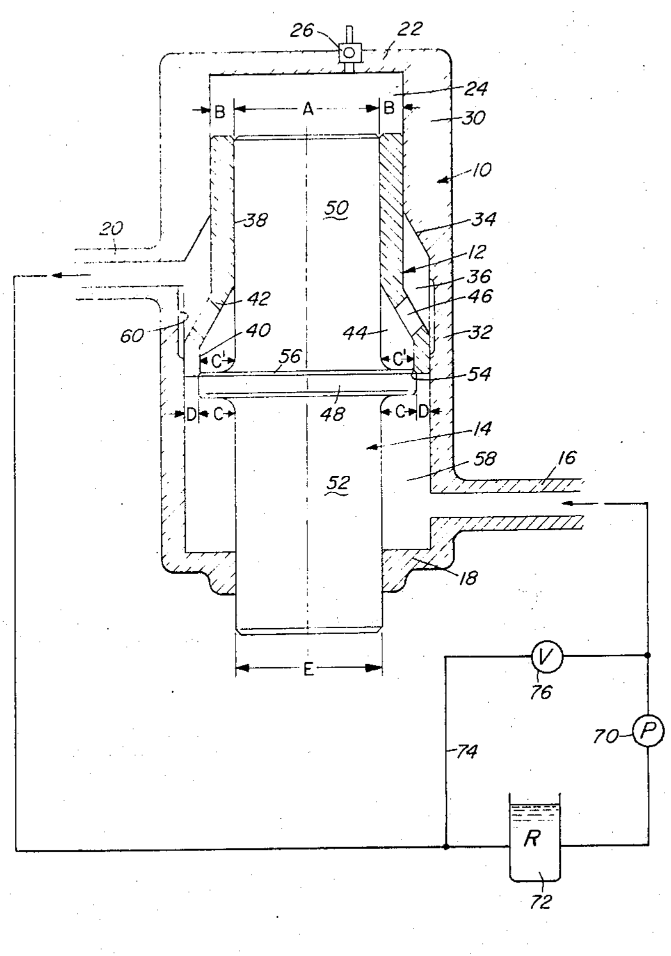
Primary Examiner—Edgar W. Geoghegan
Attorney, Agent, or Firm—Wolf, Greenfield & Sacks

[57] **ABSTRACT**

An hydraulic actuator including a cylinder, a sleeve slidable in the cylinder, and a piston slidable in the sleeve with an impacting end extending out of the cylinder. A first chamber formed in the cylinder surrounds the impact end of the piston, and energy storage means is provided in the housing at the other end, which energy storage means is in communication with the sleeve and piston. A collar is carried on the piston having one face exposed to the pressure on the first chamber and having a second opposed face which in part defines a second chamber. Means are connected to the first chamber for increasing the pressure therein to retract the sleeve and piston in unison so as to develop stored energy in the energy storage means, and means are provided for equalizing the pressures on opposite faces of the collar as the piston and sleeve retract to release the stored energy to drive the piston in a power stroke in the direction of the impacting end and also causing the stored energy to drive the sleeve in the same direction. The second chamber is constantly open to the atmosphere.

15 Claims, 14 Drawing Figures



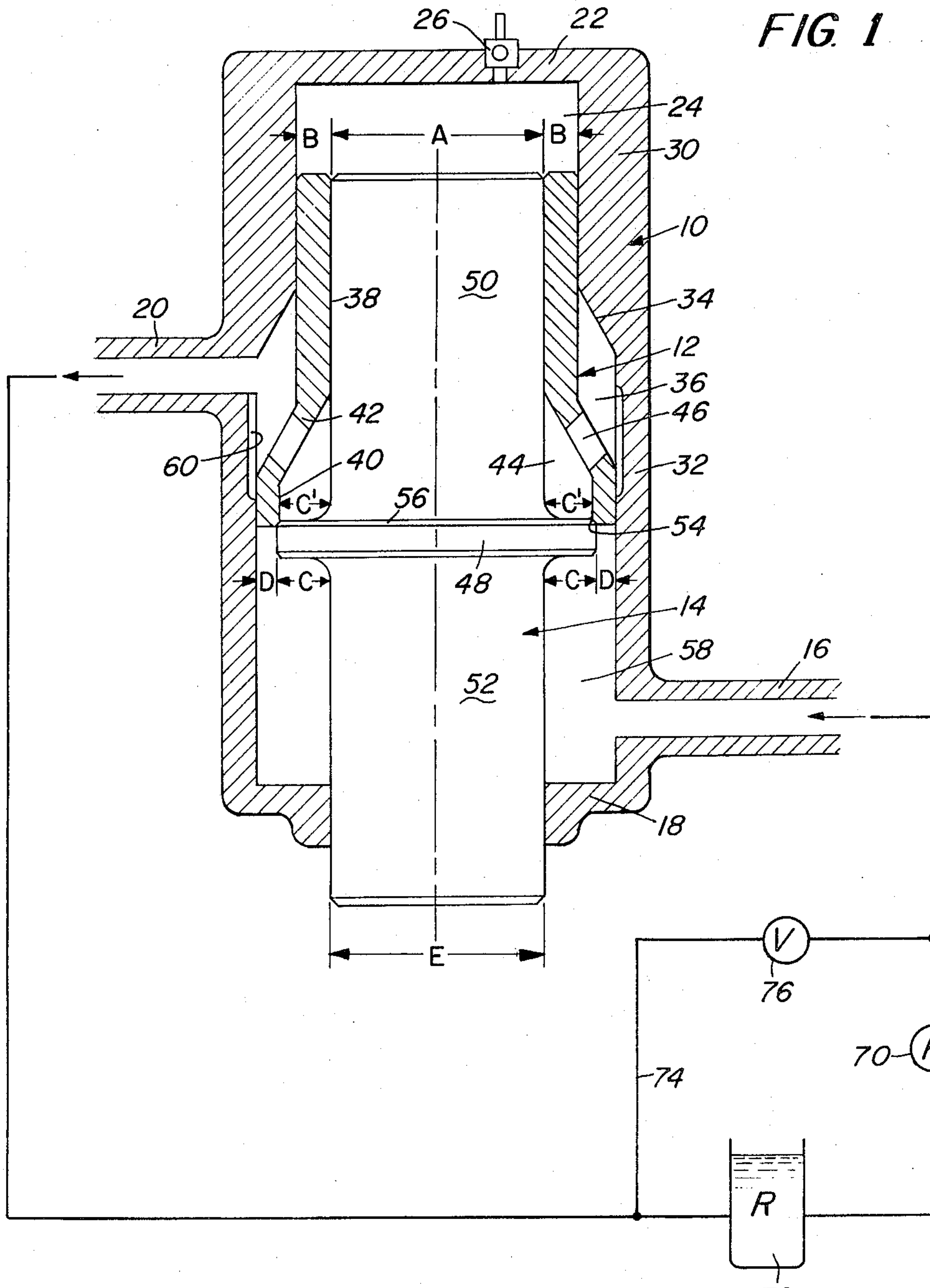

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FIG. 1

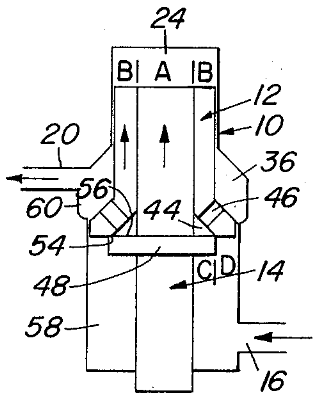

FIG. 2

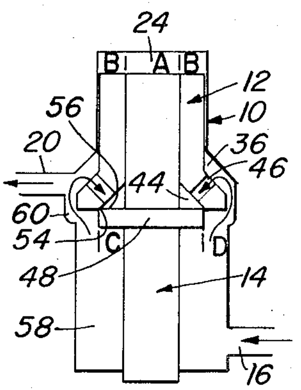

FIG. 3

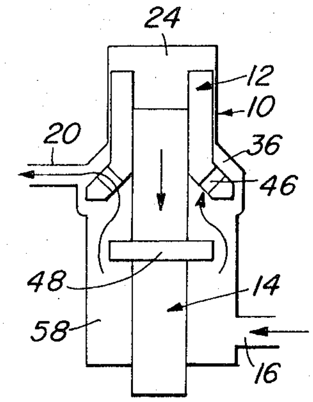

FIG. 4

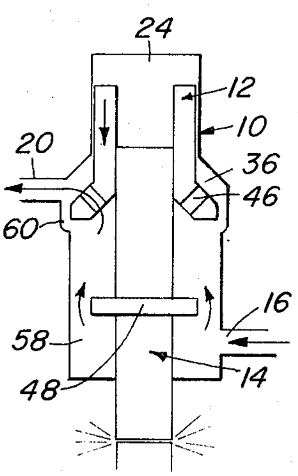

FIG. 5

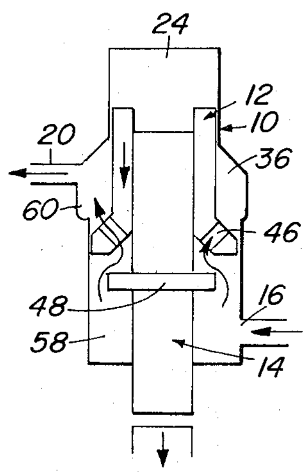

FIG. 6

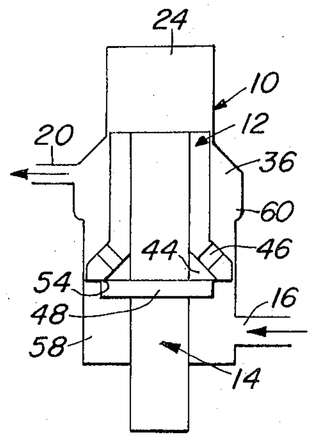

FIG. 7

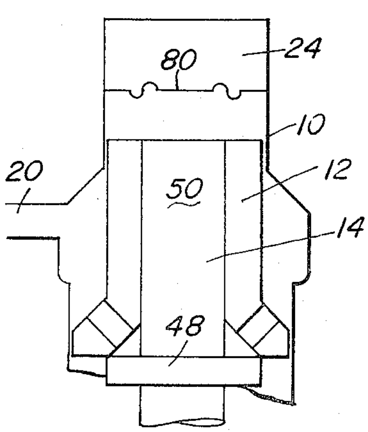

FIG. 8

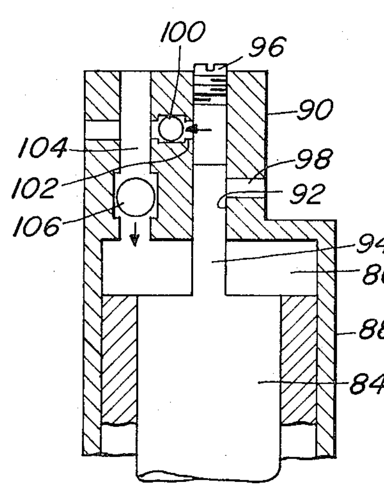

FIG. 9

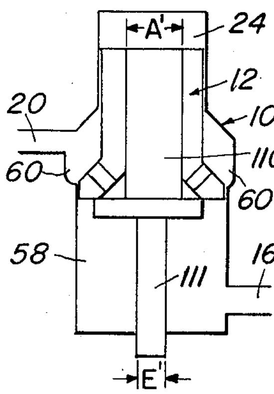

FIG. 10

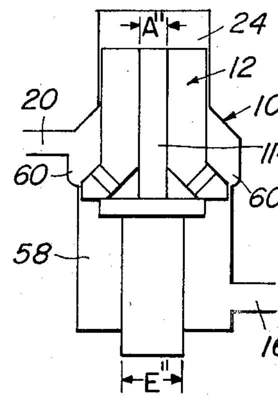

FIG. 11

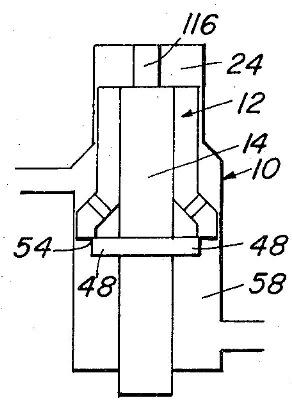

FIG. 12

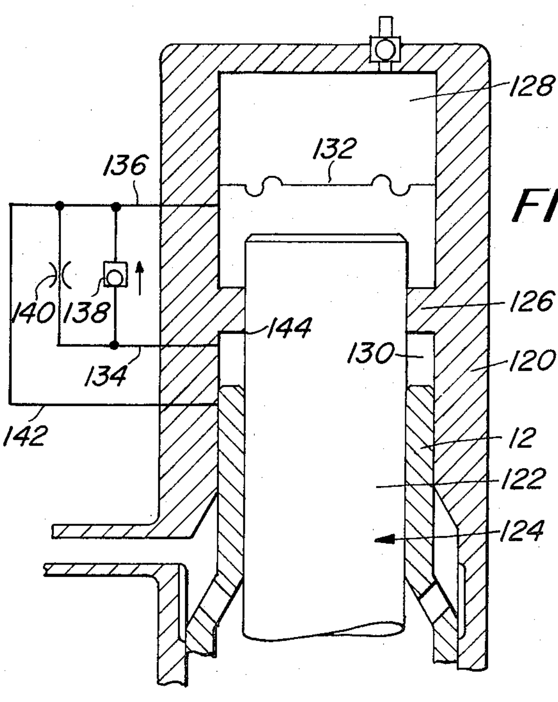

FIG. 13

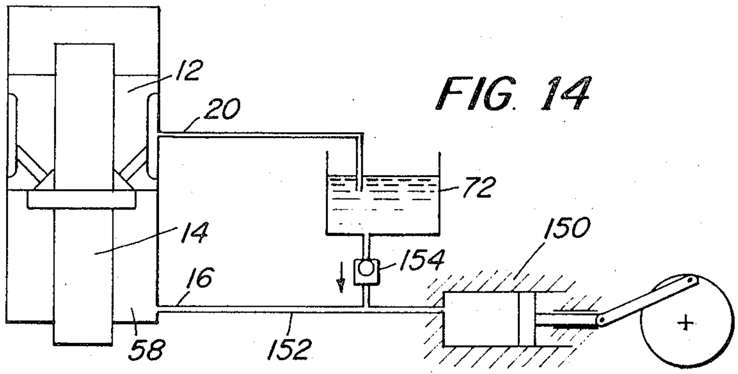

FIG. 14

HIGH ENERGY RATE ACTUATOR

BACKGROUND OF THE INVENTION

This application relates to high velocity hydraulic actuators and more particularly comprises an improvement over the actuator disclosed in application Ser. No. 91,651 filed Nov. 23, 1970, now abandoned assigned to Foster-Miller Associates, Inc.

The actuator of the present invention is suitable for use in many applications including rock drills, pavement breakers, punch presses, forging hammers, nail drivers, etc. The actuator may be operated either as a single or repetitive cycle device.

High velocity actuators normally deliver very high instantaneous power during the power stroke. However, high velocities are not compatible with conventional "steady flow" hydraulic systems for reasons both of excessive fluid velocity losses and very high instantaneous power. Consequently, actuators are designed to store energy at modest power levels to be released at a high rate during the power stroke.

Prior to the invention disclosed in application Ser. No. 91,651, supra, actuator design was very complex. The complex designs are particularly detrimental in those applications which require an impact as the useful power output, because the complex designs are not readily capable of withstanding the very substantial shocks which are imposed on the systems in those applications. The invention disclosed in application Ser. No. 91,651 represents a substantial improvement over the prior complex designs for it reduces the number of moving parts essentially to three; namely, a piston, sleeve, and valve, and it accepts a constant flow rate as the motivating force so as to enable the actuator to be powered by commonly available fixed displacement power supplies.

Nevertheless, the design of the actuator shown in the earlier application Ser. No. 91,651, now abandoned had certain disadvantages. For example, in that system the exhaust flow of motivating fluid fluctuates from zero to some high value during each cycle. The high value may be as much as several times the normal inflow rate, depending upon the cycle rate of the actuator. Furthermore, the central valve forming part of the preferred embodiment of the actuator of that application represents a potential source of maintenance problems, particularly because it must cycle once for every cycle of the piston-sleeve assembly.

One important object of the present invention is to provide an actuator with a very simple mechanical operation, which permits energy storage in a compressed gas and quick release of that energy without excessive fluid velocities or pressure surges. Consequently, the simple mechanical configuration is conducive to the adoption of simple, rugged piston and sleeve shapes suitable for impacting service.

Another important object of this invention is to provide a high velocity actuator which is free of external control valves that are potential sources of maintenance problems.

BRIEF FIGURE DESCRIPTION

FIG. 1 is a cross section view of an actuator constructed in accordance with this invention and schematically shown connected to a hydraulic control circuit;

FIGS. 2–7 are schematic drawings of the actuator of FIG. 1 sequentially illustrating the positions of the various parts of the actuator during a single cycle; and

FIGS. 8–14 are schematic drawings, some fragmented, of other embodiments of this invention.

DETAILED DESCRIPTION

The actuator assembly shown in FIG. 1 essentially includes three parts, namely, housing **10**, sleeve **12**, and piston **14**. For simplicity, piston rings and other forms of seals which may be utilized have been omitted in the drawing. Housing **10** and sleeve **12** are shown to have upper diameters smaller than their lower diameters, unlike the embodiments illustrated in earlier application Ser. No. 91,651. However, this particular arrangement is not essential to the operation of this invention, and the diameters may be uniform throughout.

Housing **10** includes an inlet **16** adjacent its bottom wall **18**, and an exhaust port **20** approximately centrally located between the top **22** and bottom **18** of the cylinder. Cylinder top wall **22** defines with the top of sleeve **12** and piston **14** an enclosed gas chamber **24**. Top wall **22** of the housing is fitted with a check valve **26** used to charge the chamber **24** with gas.

The upper cylindrical portion **30** and lower cylindrical portion **32** which together define the housing **10** are joined at their inner surfaces by frustoconical section **34**, which with sleeve **12** defines an annular hydraulic volume **36** in constant communication with the port **20**. The upper smaller diameter portion **38** of sleeve **12** is joined to lower cylindrical portion **40** of the sleeve by frustoconical section **42**, which in turn defines with the piston a second annular hydraulic volume **44**. Hydraulic volumes **36** and **44** are in constant communication with one another through the ports **46** formed in frustoconical section **42** of sleeve **12**.

Piston **14** as shown in the drawing is essentially rod shaped but includes a collar **48** of greater diameter than either the upper portion **50** or lower portion **52** of the piston.

A chamfered seat **54** is formed in the lower end of sleeve **12**, that serves as a valve seat for the beveled edge **56** of collar **48** which mates with it. When the sleeve and piston are in the position shown in FIG. **1**, volume **44** is sealed from the lower chamber **58** formed in housing **10** about the lower end **52** of the piston.

Sleeve **12** slides freely in housing **10**, and piston **14** slides freely in the sleeve, and a sliding seal exists between upper cylindrical portion **38** of the sleeve and upper portion **30** of the housing. Similarly, a sliding seal is effected between upper portion **50** of the piston and the inner surface of the upper portion **38** of the sleeve.

To assist in understanding the description of the operation of the actuator which follows, certain areas of the sleeve and piston have been labeled with letters which are used in the equations below. Thus, in FIG. **1**, area A represents the upper end of piston **14**, B represents the area of the upper end of sleeve **12**, C represents the area of the collar **48** exposed to the pressure chamber **58**, D represents the area of the lower end of sleeve **12** exposed to the pressure chamber **58**, and E represents the area of the exposed end of piston **14**.

In FIGS. **2–7**, the operating cycle of the actuator of FIG. **1** is illustrated. In describing this operation it is assumed that the inlet **16** is connected to a constant source of flow as may typically be established by a gear pump. And at all times during the cycle, the discharge port **20** is open to the atmosphere.

In FIG. 2 the pressure P_{58} (pressure in chamber **58**) drives piston **14** and sleeve **12** upwardly against the gas pressure P_{24} in chamber **24** by acting on area C of collar **48** and area D of sleeve **12**. Thus the piston and sleeve combination move upwardly in unison.

To assure that the piston and sleeve are held together the following inequalities must be established.

[1] $P_{58}C > P_{24}A$ and

[2] $P_{24}B > P_{58}D$

Because in the embodiment shown area C is larger than area A and area B is greater than area D, the proper relationship is provided so as to insure the joint travel of the piston and sleeve as suggested in FIG. 2.

The piston-sleeve combination rises as a single body as flow into chamber **58** continues as suggested in FIG. **2** while the relationships set forth in equations **1** and **2** are maintained. As joint upward travel of piston and sleeve continues, relief passages **60** formed on the inner surface of cylindrical portion **32** of the housing **10** are exposed by the lower end of sleeve **12** to the chamber **58**. When this occurs, volumes **44** and **36** are placed in communication with the chamber **58** and the valve seat **54** and collar **48** are bypassed. This results in the equalization of the pressures on the opposite side of the collar **48** acting on areas C and C^1. When the pressures on opposite sides of the collar **48** are balanced, then the pressure P_{24} on area A creates an unbalance, and the piston is driven downwardly, breaking the seal at **54, 56** and free flow is established from chamber **58** through volume **44**, passages **46**, volume **36**, to discharge port **20**. Downward travel of the piston is impeded only slightly by flow of hydraulic fluid in the chamber **58** about collar **48** through annular area D. Consequently downward movement of the piston is very rapid, with the accelerating force approximately equal to $P_{24}A$.

With the seal at the valve seat **54** broken, the pressure drop across collar **48** from area C to C^1 instantaneously becomes zero. If the cross sectional areas A and E of the upper and lower portions of the piston are equal, downward motion of the piston does not displace fluid, and the piston moves downwardly until stopped by some useful impact as suggested in FIG. 5. With the piston and sleeve separated, the hydraulic fluid in chamber **58** is free to exhaust through volume **44**, passages **46**, volume **36**, to discharge port **20**. Consequently the pressure **58** is sharply reduced, assuming a fixed inlet flow. If volume **44**, passages **46**, volume **36** and port **20** are large, the gas pressure in chamber **24** acting on area B will rapidly drive the sleeve **12** down as shown in FIG. 6. The descent rate of the sleeve depends on the restriction of those passages and volumes. The sleeve descends, passing the relief passages **60** until a seal is again formed at the valve seat **54** as suggested in FIG. 7.

The sleeve is able to form a seal at valve seat **54** to close off flow at that area because of the force relationships expressed in equations [1] and [2] above. That is, the downward force on the sleeve closes the valve seat until the pressure in chamber **58** (P_{58}) rises sufficiently to create an upward force on the piston and sleeve areas C and D causing the piston and sleeve to rise again as a unit in the manner suggested in FIG. 2.

In FIG. 1 the system which includes the actuator is suggested schematically. A pump **70** is shown connected to inlet duct **16** for providing a constant inlet flow to the chamber **58**. The pump is shown supplied by a reservoir **72** which in turn is connected to discharge duct **20**. The actuator may be shut off by shunting the housing **10** as suggested by line **74** in the system, which contains an on-off valve **76**.

The present invention is susceptible to several modifications. Some of these are suggested in FIGS. **8** to **14** described below.

In FIG. **8**, a flexible membrane **80** is shown extending across the chamber **24** so as to positively seal that chamber. Consequently, hydraulic fluid may act on the top of the sleeve and piston through the diaphragm, and a positive seal is provided to prevent any loss of the fluid in chamber **24**.

FIG. **9** shows another embodiment of the invention wherein the reciprocating motion of the piston **84** is employed to power a self-contained compressor which feeds the gas chamber **86** so as to maintain the pressure in the chamber above some minimum level. In accordance with this embodiment, housing **88** is provided with an upper extension **90** having a bore **92** which slidably receives the upper end of piston rod **94** carried by the piston **84**. The upper end of the bore **92** is closed by adjustable plug **96**, and a port **98** is provided in the extension in communication with the bore.

As the piston **84** moves downwardly during the power stroke, air flows into bore **92** through inlet port **98** when the upper end of rod **94** drops below the port, and when piston **84** moves upwardly and rod **94** again closes port **98** the entrapped air in the bore is compressed and ultimately discharges through the check valve **100** located in exhaust port **102**.

A second bore **104** closed at its outer end communicates directly with chamber **86**, and a check valve **106** in the bore controls flow from the bore **104** to the chamber **86**. When the pressure in chamber **86** falls below a selected value, the check valve **106** will open to permit air to pass into chamber **86**. This will occur only when the piston and sleeve are at the bottom of their stroke. Consequently, pressure in the chamber **86** is maintained at a minimum predetermined value corresponding to the maximum pressure within the bore **92**. Plug **96** may be adjustable to vary the volume of the bore **92** so as to adjust the predetermined minimum pressure value for chamber **86**.

When starting the actuator, it may be necessary to cycle the device a few times to achieve the desired pressure level. The variable bore volume **92** provided by plug **96** may be adjusted to limit the peak pressure within the compressor which, in turn, and in cooperation with check valves **100** and **106** become the minimum gas pressure in chamber **86**.

In FIG. **10** yet another modification is shown. In this embodiment, the diameter A′ of upper piston **110** is greater than the diameter E′ of lower piston portion **111**. Consequently, when the piston descends during the power stroke, it must displace fluid in chamber **58**, and this tends to be accommodated by an upward acceleration of the sleeve. As a result, sleeve descent is delayed, which counteracts piston recoil effects.

In FIG. **11** another embodiment of the invention is shown wherein the cross sectional area A″ is smaller than the cross sectional area E″ of the lower end of the piston (an arrangement opposite to that shown in FIG. **10**). In this configuration, as the piston **114** descends during the power stroke, the negative change in volume of the piston in chamber **58** tends to draw fluid into the chamber, which is accommodated by a downward acceleration of sleeve **12** until piston **114** stops. This configuration results in a shorter cycle time than would otherwise exist.

In FIG. **12** still another embodiment is shown. In accordance with this embodiment, the relief passages **60** are omitted, and a stop **116** is provided in the chamber **24** of housing **10** to arrest upward movement of the piston during the retraction portion of the cycle. It will be apparent that when the piston retracts to a position wherein it engages stop **116** as shown in FIG. **12**, continued inflow of hydraulic fluid into chamber **58** will cause the sleeve to continue to rise and unseat collar **48** from valve seat **54**. Consequently, when the seal is broken, the piston will immediately fire in the power stroke of the cycle in accordance with the teachings of the other embodiments.

The embodiment of FIG. **13** includes means for controlling the descent rate of sleeve **12** which accordingly controls the cycle time of the actuator. In accordance with this embodiment, the upper end **122** of piston **124** is somewhat elongated, and a partition **126** is provided in chamber **128** in sealing engagement with the piston extension. Sleeve **12** defines a volume **130** about the piston below the partition **126**.

A diaphragm **132** is also shown in FIG. **13** extending across chamber **128** in the manner of the embodiment shown in FIG. **8**. However, that diaphragm is not essential to the operation of the device, but merely assures a positive seal in the chamber.

As piston **124** and sleeve **12** move upwardly together in housing **120**, fluid in volume **130** is free to flow into chamber **128** below diaphragm **132** through ducts **134** and **136** connected by check valve **138** which is free flowing in only the direction indicated by its arrow. After the piston is fired in the manner described in connection with FIG. **1**, sleeve **12** is restricted in its downward motion because fluid can enter the volume **130** only through the orifice **140** which also joins ducts **134** and **136**. By adjusting the orifice size, the velocity of the sleeve in its downward travel may be varied.

Further control of sleeve descent may be achieved by the addition of a duct **142** which joins the volume **130** somewhat below the top of sleeve **12** when in its retracted position. That is, when the sleeve **12** is in its uppermost position, the duct **142** is closed so as to bar flow from chamber **128** below diaphragm **132** to the volume **130** through it. However, when the sleeve descends in its downward stroke and uncovers the duct **142**, the orifice **140** is bypassed and flow is allowed freely from chamber **128** below diaphragm **132** to volume **130**. Thus, the sleeve descent rate will increase after duct **142** is uncovered by the upper end of the sleeve.

Referring again to FIG. **13**, yet another means of achieving a delay of sleeve descent is suggested. In accordance with this embodiment, the duct **142** may be eliminated as well as orifice **140**. In the absence of orifice **140** and duct **142**, the descent of sleeve **12** would be delayed until the top of piston extension **122** passed below the point **144**. When the piston drops below that point, free communication is established between chamber **128** below diaphragm **132** and volume **130**, and sleeve descent would thereupon be unrestricted as in the embodiment of FIG. **1**.

In FIG. **14** yet another modification is shown. In accordance with this embodiment, the constant flow actuation is replaced by an alternating power supply in the form of a reciprocating pump **150**. The pump is connected to chamber **58** by duct **152**, and the discharge port **20** is connected to reservoir **72** which in turn is connected to duct **152** through check valve **154**. The check valve limits flow only in the direction from the reservoir to the duct as suggested by its arrow.

In accordance with this embodiment, displacement of the pump in a direction to drive fluid into chamber **58** is sufficient to cock the piston-sleeve assembly, and the excess fluid present in chamber **58** during the compression stroke of the piston is discharged through port **20** after the piston **14** has fired and separated from sleeve **12**. The flow in duct **152** may oscillate back and forth between the pump and chamber **58** as the pump reciprocates. If desired, a check valve (not shown) may be inserted in duct **152** to permit flow only in one direction, namely, from pump **150** to chamber **58**.

It will be appreciated that in all embodiments where the two ends of the piston are of the same diameter, the piston may be made precisely symmetrical so as to permit reversing the piston to double its life. It will also be appreciated that the frequency of the cycle may be controlled by providing throttling valves in the discharge port or by introducing restrictions in the passages **46**. Alternatively, frequency may be controlled by providing means for varying the inlet flow rate to chamber **58** from the pump.

It will be appreciated that the actuator disclosed in this present application is of simple design capable of producing high impact velocities. In each embodiment the velocity is achieved by initially compressing a gas or some other energy storage means and then applying that force of stored energy to the piston without requiring rapid liquid displacement. The actuator lends itself to a variety of control techniques as suggested above, and it may be operated to provide fully automatic, continuous operation, semi-automatic operation, or single blow operation.

It will also be appreciated that the foregoing description is intended merely to be illustrative of the invention and that other embodiments may occur to those skilled in the art. Therefore, it is not intended to limit the breadth of this invention to the embodiments illustrated and described. Rather, it is intended that the scope of this invention be determined by the appended claims and their equivalents.

What is claimed is:

1. An hydraulic actuator comprising

a cylinder,

a sleeve slidable within the cylinder and forming a seal with the inner surface of the cylinder at one end thereof,

a piston slidable in and forming a seal with the sleeve at said one end and having an impacting end extending out the other end of the cylinder,

a first chamber in the cylinder at said other end defined in part by said other end of the cylinder and the other end of the sleeve and surrounding the impacting end of said piston,

a sealed gas filled second chamber at said one end of the cylinder and defined in part by the adjacent ends of the sleeve and piston,

a collar carried on the piston and having a face which is exposed to the first chamber,

means connected to the first chamber for increasing the pressure therein to retract the sleeve and piston in unison in the direction of the sealed chamber to develop stored energy in the sealed chamber by the compression of the gas therein,

a second face on the collar of the piston opposed to the first recited face and a third chamber defined in part by the second face, said third chamber being constantly open to the atmosphere, and

means for equalizing the pressures on the opposite faces of the collar as the piston and sleeve move toward the sealed second chamber to cause the pressure in the sealed chamber to drive the piston rapidly in a power stroke in the direction of the impacting end of said piston, said last-mentioned means causing the pressure in the first chamber to drop sharply and thereby permitting the pressure in the sealed chamber to drive the sleeve in the direction of said first chamber.

2. An hydraulic actuator as described in claim **1** further characterized by

said means for equalizing the pressure in the second chamber being a fluid duct bypassing the collar when the piston and sleeve are retracted beyond a predetermined position within the houing.

3. An hydraulic actuator as described in claim **1** further characterized by

said means for equalizing the pressure in the second chamber being a stop provided in the housing for physically limiting the extent the piston may be retracted in the housing.

4. An hydraulic actuator as described in claim **2** further characterized by

said fluid duct being formed in the inner surface of the housing.

5. An hydraulic actuator as described in claim **1** further characterized by

the inner diameter of the cylinder at said one end which defines the sealed chamber being smaller than the diameter of the other end of the cylinder which defines the first chamber,

the end of the sleeve in part defining the first chamber forming a sliding seal with the inner surface of said other end of said cylinder.

6. An hydraulic actuator as described in claim **1** further characterized by

said sleeve in part defining said third chamber and forming a valve with the collar separating the third chamber from the first chamber as the sleeve and piston retract in unison in the housing,

said valve opening to connect the first and third chambers when the sleeve and piston move relative to one another.

7. An hydraulic actuator as described in claim **6** further characterized by

a relatively large constantly open port in the sleeve communicating with the third chamber and connecting the third chamber to the atmosphere.

8. An hydraulic actuator as described in claim **5** further characterized by

said sleeve in part defining said third chamber and forming a valve with the collar separating the third chamber from the first chamber as the sleeve and piston retract in unison in the housing,

said valve opening to connect the first and third chambers when the sleeve and piston move relative to one another.

9. An hydraulic actuator as described in claim **8** further characterized by

a relatively constantly open port in the sleeve communicating with the third chamber and connecting the third chamber to the atmosphere.

10. An hydraulic actuator as described in claim **6** further characterized by

the area of the end of the piston exposed in the sealed chamber being substantially equal to the area of the impact end of the piston extending out of the chamber.

11. An hydraulic actuator as described in claim **6** further characterized by

the area of the end of the piston exposed to the sealed chamber being greater than the area of the impact end of the piston extending out of the chamber.

12. An hydraulic actuator as described in claim **6** further characterized by

the area of the end of the piston exposed to the sealed chamber being smaller than the area of the impact end of the piston extending out of the chamber.

13. An hydraulic actuator comprising

a cylinder,

a sleeve slidable within the cylinder,

a piston slidable in the sleeve and having an impacting end extending out of the cylinder,

a first chamber in the cylinder defined in part by said cylinder and sleeve and surrounding the impacting end of said piston,

energy storage means in the housing associated with the remote end of the piston,

a collar carried on the piston and having a face which is exposed to the first chamber,

means connected to the first chamber for increasing the pressure therein to retract the sleeve and piston in unison in the direction of the energy storage means to develope stored energy in said means,

a second face on the collar of the piston opposed to the first recited face and another chamber defined in part by the second face, said other chamber being constantly open to the atmosphere, and

means for equalizing the pressures on the opposite faces of the collar as the piston and sleeve retract to permit the stored energy to drive the piston rapidly in a power stroke in the direction of the impacting end of said piston, said last mentioned means causing the pressure in the first chamber to drop sharply and thereby permitting the stored energy to drive the sleeve in the direction of said first chamber.

14. An hydraulic actuator as described in claim **13** further characterized by

said sleeve in part defining said other chamber and forming a valve with the collar separating the other chamber from the first chamber as the sleeve and piston retract in unison in the housing,

said valve opening to connect the first and other chambers when the sleeve and piston move relative to one another.

15. An hydraulic actuator as described in claim **14** further characterized by

a relatively large constantly open port in the sleeve communicating with the other chamber and connecting the other chamber to the atmosphere.

* * * * *