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Pauliukonis

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[54] **ENERGY CONSERVING DIRECTIONAL VALVE-CYLINDER COMBINATION**

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[52] **U.S. Cl.** **91/416,** 91/459, 91/461, 92/152

[51] **Int. Cl.** **F15b 15/17,** F15b 13/044

[58] **Field of Search** ..... 91/416, 417 A

[56] **References Cited**

UNITED STATES PATENTS

3,469,400	9/1969	Oikawa et al.	91/416
3,645,170	2/1972	Varouxis	91/416
3,683,748	8/1972	Nlahl	91/416

Primary Examiner—Paul E. Maslousky

[57] **ABSTRACT**

This invention relates to directional control valves designed to conserve fluid energy when serving power cylinders, and more particularly to an energy conserving TANDEM DIRECTIONAL VALVE-CYLINDER COMBINATION utilizing a solenoid valve of simple SPRINGLESS three component design to operate a specially designed power cylinder of differential diameter piston allowing the pressurized fluid to energize the piston of smaller area to do work and to return this piston to the original position by the exhaust of the same working fluid when work is completed, acting over the larger piston area in tandem action with pressurized working fluid passing through the passages of the directional control valve allowing for energy conservation with resultant savings to the user of such unit in automation, instrumentation and miniaturization fields.

6 Claims, 5 Drawing Figures

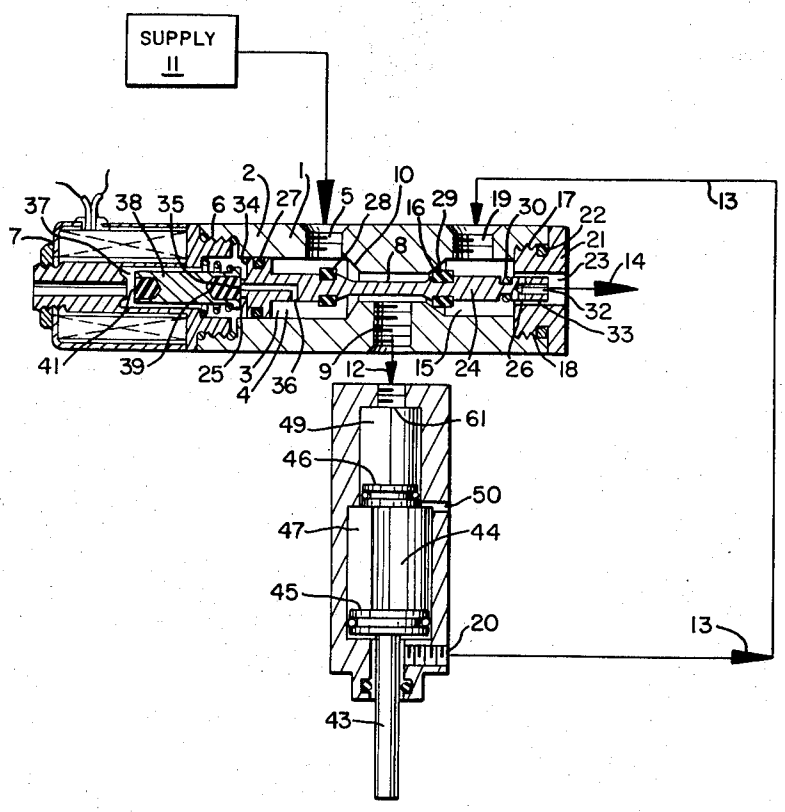


FIG. Ia

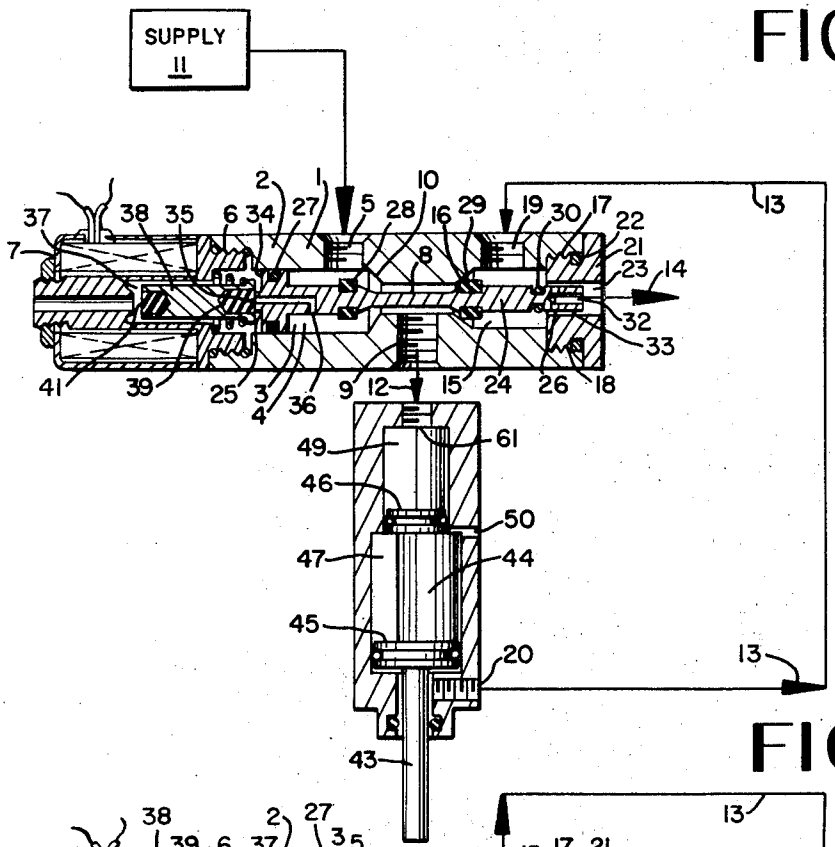


FIG. Ib

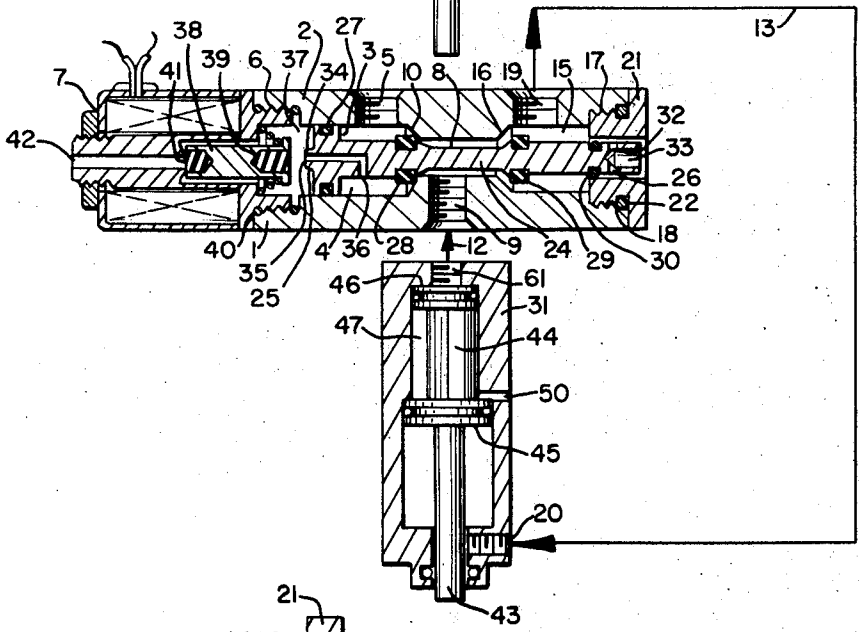
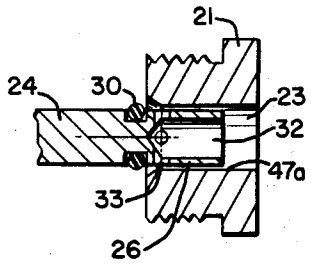


FIG. Ic



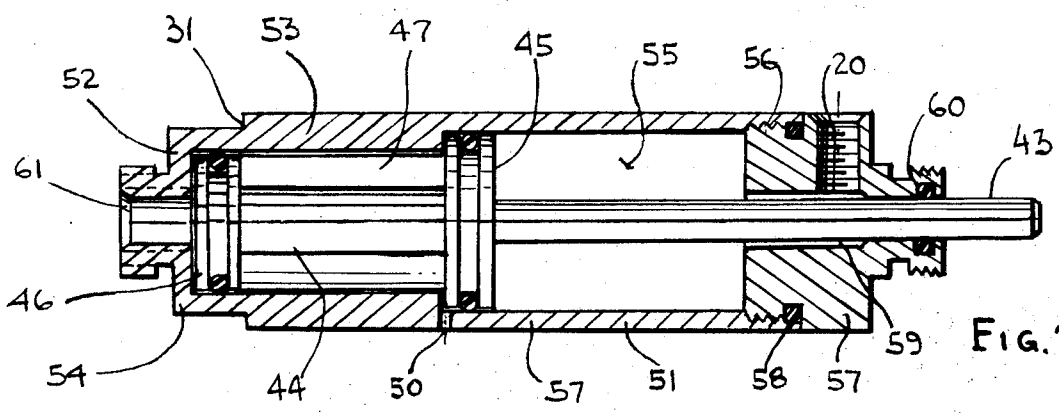

31
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59

FIG. 2

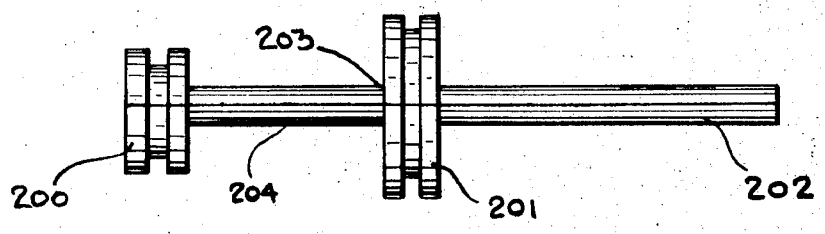

203
200
204
201
202

FIG. 3

ENERGY CONSERVING DIRECTIONAL VALVE-CYLINDER COMBINATION

This invention thus has application in Fluid Power Industry which employs directional valves of a two-way, three-way and four-way design for cylinder actuation, or in Process Industry for control of operating reciprocating pumps, or as shut-off valves.

Conventionally a three-way valve operator controls the action of a single acting-spring return power cylinder, and a four-way valve operator controls the operation of a double acting cylinder.

The two-way or three-way or four-way valves may be of manual or solenoid types. Generally a three-way valve serving a single acting cylinder, which is normally returned by a spring to the original position after the valve is opened to exhaust requires the working fluid to overcome spring resistance in addition to the work load designated for each cylinder, with spring resistance force representing a sizeable energy requirement. Further, the use of a spring in a cylinder requires extra length of cylinder body which in double acting cylinders is not needed. Obviously, devices that would not require springs, and could not utilize exhaust of the working fluid to replace the double acting cylinder function, with a single input of the working fluid are needed.

A four-way valve serving double acting cylinders as a rule is more complicated. In many a case the use of a four-way valve causes cylinder deterioration prematurely, imparticular if the application calls for unidirectional load service: upon return from the second energized working position to the first partially loaded position, the cylinder becomes heavily abused due to the full force the working fluid exerts, while changing position, against the cylinder ends. The result is energy waste and product deterioration at great cost to the user, imparticularly where pressure reducers are employed to purposely reduce the impact load of the partially loaded position change of the piston, great waste of both the energy and the additional equipment cost is passed over to the user at the expense of ignorance as the reducers are inefficient.

It is therefore the object of the present invention to improve operation of both the three-way valve serving a single acting-spring return cylinder which necessitates extra material for cylinder body length, the spring itself and energy addition all of which can be rather costly, although unavoidable within existing state of the art, and of the four-way serving a double acting cylinder with drastically improved efficiency and extended service duration due to innovation offered by this invention.

It is further object of this invention to provide a directional control valve designed to conserve fluid energy when serving power cylinders in valve-cylinder combination.

In one application this type of tandem directional valve has successfully operated two single acting-spring return cylinders in series, with the exhaust of the first cylinder feeding and actuating the second cylinder when solenoid was energized, and finally escaping to the outside via an exhaust port after returning second cylinder to the first position-deenergized, while the first cylinder became fully energized the moment the solenoid was deenergized, all by the pressurized working fluid that entered the normally open first cylinder to

continue in tandem flow to energize and feed the second cylinder at will until final exhaust of the working fluid to the outside.

In another application this tandem valve has successfully operated a double acting cylinder. But, rather than the pressurized fluid doing the work, the exhaust fluid moved the piston forward in the conventional cylinder under reduced load. It should be noted here, that the accepted practice to do the work is by pushing the piston-rod under load forward with the full force of the pressurized working fluid. In the application being discussed here in which a conventional cylinder was employed in conjunction with the tandem valve cited, more efficient performance and greater work could have resulted by way of piston retraction rather than forward push, because the design of the conventional cylinder with piston area larger at blind end does not lend itself to be controlled by this tandem valve, and to do work by a forward motion, unless the cylinder components such as piston & rod assembly were redesigned, as proposed by this invention.

In applications such as reciprocating pumps that employ power cylinder-piston rods for displacement of fluids under load when energized by pneumatic/hydraulic working fluids, the piston is required to move forward under load opposed by the pumping fluid force, or being moved by the pressurized working fluid to extend under load rather than retract: the retraction of the piston rod in such pumps is not associated with useful work, and normally needs little force for the position change of the piston-rod assembly to the retracted first piston-rod position, and subsequent push and extension of the rod to the second position for performing the useful work of pumping. Obviously this tandem valve could be used successfully to do the pulling work by retracting piston rod of a conventional power cylinder in some applications where no forward load needs to be considered, but such applications are rather few. Rare are the applications cited above but while illustrating versatility of tandem valve, they show applications with push forward under load and retract the piston-rod assembly under reduced load w/less force, or vice-versa.

The principal object of this invention is therefore to provide a valve-cylinder combination that would be capable of performing a useful forward motion under load resulting in work with maximum force of the working fluid under pressure entering such a directional valve during the normally open valve position for cylinder actuation, and subsequent return of the cylinder exhaust back into the valve for an external retraction of the piston-rod at the end of such useful forward motion and work to the original position of the piston rod by the same working fluid in a sequence that provides not only great economical gains in energy utilization but also preserves the integrity of the power cylinder physically, as the return of the piston-rod to the original first position is not accompanied by the full force of the working fluid, common to a four-way valve actuation, but is gently returned by expanded fluid that does the piston or piston-rod return function, for free, by otherwise not utilized cylinder exhaust.

To do this operation most economically, it was necessary to redesign the conventional cylinder, and to provide a differential area NOVEL PISTON, in order to expose larger areas of the piston to the lower exhaust pressure of the working fluid, that leaves cylinder after

the forward motion of the piston is completed, for piston return to the original position, with smaller piston area experiencing full pressure of the working fluid initially, via an inlet port of the valve in direct communication with the cylinder port facing smaller piston to do such work as is required, and in proportion to the forces needed for the return of subject piston to the original first position, for the subsequent sequential pressurization, work and return cycle associated with double acting cylinders, but by the use of the same working fluid passing through the appropriate valve passages in tandem in this valve-cylinder combination.

Although both the tandem directional valve and the unconventional power cylinder of this invention retain their certain specific individual generic characteristics relative to their function individually, and as such each may become useful tools when employed in some applications separately, it is felt that the largest benefit of this innovation can materialize by combining these individual components into an integral unit called a valve-cylinder combination. After all, there is no cylinder that can function without a directional valve, be it manual or solenoid type, and this combination will provide a revolutionary unit for better performance, at less cost, with improved quality because of a rather unique simplification of this valve-cylinder combination, and a drastic departure from the existing state of the art in designs of similar cylinder-valve combinations presently marketed. In fact, this invention may be considered a breakthrough of the century in fluid power equipment design, as there were many attempts to conserve energy in such or similar applications without success before, and as such has been a dream of many professionals-inventors in the past.

Other objects and advantages of this invention relative to both, the energy conserving tandem valve and the power cylinder of unconventional design, separately and in combination, will become more fully apparent as the description proceeds in accordance with the drawings in which:

FIG. 1–*a* is a cross-sectional view of the valve, identifying basic design components of the valve, with valve normally open and valve stem positioned so as to allow the cylinder feed with the pressurized fluid from the supply source to the receiver, namely the power cylinder, causing piston-rod extension as illustrated diagrammatically in the cylinder connected to the valve, with valve exhaust open.

FIG. 1–*b* identifies valve with position change of both the valve stem, shown in detail and illustrating cylinder support port closed while the cylinder exhaust port is open for tandem flow of the fluid along the valve body, and the retraction of the piston rod, while valve exhaust is closed.

FIG. 1–*c* is a partial cross section of stem end of FIGS. 1–*a* & 1–*b* enlarged.

FIG. 2 is a cross-sectional view of the power cylinder with differential piston area, and other details of importance and novelty identified with piston rod retracted, comprising original first load free position of the piston-rod assembly and prior to its pressurization for the position change and work.

FIG. 3 identifies differential diameter piston-rod assembly separately.

Refering to the drawings and particularly to FIG. 1–*a* we find a directional tandem valve **1** receiving pressurized working fluid from a source such as identified by **11** to a receiver **31** such as power cylinder inlet end **61**, through a conduit indicated diagrammatically at **12**, & representing normally open valve adapted to control the fluid flow for cylinder feed and exhaust, while conduit **13** with directional arrows identifies flow of fluid away from the cylinder opposite end for exhaust through the valve opening identified by arrow at **14**.

Turning to the description of valve **1** in more detail, it is seen to include a central elongated housing member **12** having an axially extending cylindrical bore **3** therein. Bore **3** has an enlarged annular portion **4** communicating directly with inlet port **5** which may be threaded. One end of bore **3** is further enlarged and threaded at **6** to receive a solenoid operator **7**, at the end of annular portion **4** of which the opposite end becomes reduced resulting in smaller diameter annular portion **8** in direct communication with cylinder feed end-perpendicular-port **9** which is threaded for a close and rigid mounting of the tandem valve to the clyinder **31** shown diagrammatically. Port **9** feed small piston **46** of blind cylinder end. A tapered shoulder **10** separating annular portions **8** and **4** of the bore **3** serves ideally as sealing shoulder means for closing fluid communication between inlet port **5** and cylinder feed port **9**. Past the cylinder feed port **9** the reduced annular portion **8** of the bore **3** again increases in size resulting in an enlarged annular portion **15**, including another tapered shoulder **16** that can ideally serve as sealing shoulder means for closing communication of the working fluid between annular portions **8** and **15**, when needed. The annulus **15** at the extreme bore end **3**, opposite to the solenoid end, terminates with a large threaded end **17** to receive an end-cap **21** with appropriate seal **22** entering counterbore **18** provided in the end of opening **17**. Bore **23** in the end cap **21** is the main valve exhaust. Annulus **15** is provided with a perpendicularly situated fluid exit port **19** which also may be threaded, for fluid communication with the opposite cylinder end **20** via conduit **13** for piston return to the original first position by expanded fluid working over larger piston area with force larger than the opposite force at the smaller piston end when the port **9** is exhausting.

It must be noted again that when port **9** is exhausting, in reality it is supplying fluid via annular portions **8** and **15** to the port **19** for further flow via conduit **13** to enter cylinder end at **20** for piston return to the original position, and thus it is still performing work comprising the energy conservation subject to this invention. The amount of the energy conservation is strictly dependent of the package design, the sizes and strokes of both the cylinder and the valve, the differential piston area and the ultimate balance desired in terms of pressures, speed of operation and work loads with intent to extract as much energy as this package of valve-cylinder combination concept provides, in accordance with the equilibrium relationship of $P_1V_1 = P_2V_2$ and the areas of the piston design governing the overall performance of this unit. The important consideration must be given to the resistance forces and frictional characteristics of the piston in either direction, but most important—in sizing differential area for piston return to the original first position by the fluid leaving port **9** for tandem flow via passages described with relatively low energy level. The critical component of this package is the valve stem, actuated by the solenoid to shift within the valve during the fluid directional distribution, and the seals

which must provide for a leak-proof valve at each position that the stem must assume in the course of trouble free tandem directional valve-cylinder operation.

Returning to the description of valve **1**, an elongated stem **24** received slidably in the valve bore **3** has an enlarged piston head **25** at one end, and a round stem end **26** at the other stem end, opposite to the piston head **25.** A counterbore **32** with a cross drilled hole **33** perpendicular to this counterbore in the stem end **26** may be employed for increasing fluid exhaust port means to the open, at the end of each cycle, in the course of the operation of this tandem valve-cylinder combination.

In the center of the piston **25** head, facing solenoid cavity, there is a small diameter protrusion **34** with a small hole **35** centrally drilled down into the protruding extention, & further into the stem, to exit on the other side of the stem piston head at **36,** but before the first stem seal **28,** for the fluid communication between the supply port **5,** and the solenoid cavity **37** when needed. Solenoid plunger **38,** provided with elastomeric insert **39,** normally keeps this small hole **35** closed by the force of a spring **40** comprising a part of the solenoid operator. An insert **41** at the other plunger end of the solenoid operator **7** serves as sealing means for solenoid cavity **37** by closing solenoid exhaust port **42** should the solenoid become energized as may be the case during the valve operation when need arises to shift the valve stem for redirecting fluid flow, and a position change of the piston-rod from that identified in FIG. **1**–*a* to that identified in FIG. **1**–*b*.

For the purpose of directing the flow within the valve body in tandem before and after energization of the solenoid operator **7,** seals must be applied to the stem and secured permanently as follows: seal **27** must be placed over the piston head **25,** to insure separation of the annulus **4** from the solenoid cavity **37** in order to position stem as desired to either be as indicated in FIG. **1**–*a* or **1**–*b*; seal **28** must be placed over the stem at **10** separating fluid inlet port from port **9**; seal **29** must be placed over the stem at shoulder **16** to seal off annular portion **8** from annulus **15,** and a seal **30** must be located at the end of the stem **26** for sealing exhaust port **23** which in FIG. **1**–*a* permits fluid exhaust, and in FIG. **1**–*b* keeps fluid exhaust port **23** closed permitting exhaust fluid from port **9** to complete the cycle of returning extended piston rod to the original retracted position as shown in FIG. **1**–*b*, before exhausting into open as shown in FIG. **1**–*a*. Its must be understood that FIG. **1**–*a* shows solenoid deenergized, and FIG. **1**–*b* identifies solenoid energized with the position change of the stem and of the cylinder in accordance with description of unit operation that follows. To note is the fact that in the design under consideration the shifting of the valve stem **24** by the working fluid is not affected by forces normally destructive in other designs with metal to metal contact, as in teh design under consideration all forces are absorbed by the elastomer seals strategically situated so as to absorb impact forces during the position change of the stem, and thus extending life duration of such valves manyfold, imparticular if such seals are made from materials with considerably larger strength and impact values, such as those found in urethane compounds of today. With piston head **25** inside annular portion **4** of bore **3** slidably moving along the elongated valve body **1** axially, while the other extreme stem end **26** is guided inside bore **23,** the operation and the directional fluid flow within this valve according to needs is hereby insured.

It should be pointed out that the valve according to the present invention is particularly suitable for miniaturization, i.e. the valve is designed to be used as miniature valve, a term known in the pneumatic/hydraulic art, but by no means limited to it.

It should be understood that the FIGS. **1**–*a* and **1**–*b* illustrate the same tandem directional valve **1** connected to the cylinder with differential piston, except for position change of the valve stem controlling the feed and the exhaust of the working fluid within the power cylinder, which also changes the position of its piston-rod assembly. The differential area piston **44** has a small end **46** & a larger end **45** with rod **43** attached thereto, as shown in cylinder **31** with air vent **50.** FIG. **1**–*a* shows normally open valve position with valve stem location permitting direct fluid communication under pressure into the cylinder port provided with smaller diameter piston **46** for piston forward motion and subsequent conversion of the fluid pressure energy into a linear motion as manifested by the extention of the piston rod under load while doing work, at which time the opposite cylinder end with large piston diameter is connected to the valve for exhaust, and the solenoid operator shown is deenergized, with it's cavity open to atmosphere, i.e. to exhaust. Piston rod **43** of differential diameter piston **44** is in FIG. **1**–*a* extended, with working fluid filling void **49** created by displaced piston end **46,** and resulting in an additional annular space **47** between piston & cylinder, vented through an air vent **50** to prevent air lock. Annular space **47** is acting as an atmospheric breather.

In FIG. **1**–*b* the solenoid operator is energized for a quick influx and accumulation of the pressurized working fluid inside the solenoid cavity which is sealed off from the outside by the position change of the solenoid plunger, enabling a position change of the valve stem subjected to high working fluid pressure over piston head facing solenoid cavity, and subsequent shutting-off of the pressurized fluid supply to the cylinder, with smaller diameter piston, while opening passages inside the valve to enable fluid exhaust from this cylinder with smaller diameter piston, previously under pressure, for communication with the opposite cylinder end provided with larger diameter piston, and retraction of the piston-rod to the original position-load free-by the action of exhausted fluid containing less energy when redirected and thus requiring larger piston area, for the necessary position change to repeat the cycle over and over, with the working fluid performing the double action function in the cylinder, by the use of the tandem directional valve of this invention, with great savings to the user. Piston rod **43** in FIG. **1**–*b* is retracted, identifying pressure balance on both sides, not the force.

Of greatest significance to valve design is the fact that the preassembled stem with appropriate seals less one seal, permits an extremely easy valve assembly by sliding such preassembled stem through the solenoid port down into the valve body cavity until it reaches first sealing surface, by the first set of annular seals, and then becomes permanently secured by the last elastomer ring seal from the opposite valve end by the use of special proprietory tooling and method of operation in order to provide practically two component valve design, with characteristics of poppet valve in terms of speed of response, extremely large flow coefficient C_v

within rather small dimensional valve envelope and ease of maintenance, should it be needed. Adding end-cap at the valve end makes this valve a simple three component springless valve design for operation which is strictly dependent on the pressurized fluid within the valve proper, and the solenoid operator to provide shifting of the stem for a troublefree operation of this valve. As such it meets the requirements of the valve of the future with simplicity, better quality and improved performance at less cost to the user. Because the stem is physically held inside the valve proper by the last ring-seal of elastomer origin which per se not only involves novel means of valve construction but also acts as the energy absorber during the position change of the stem. It is believed that this design may substantiate the use of elastomer, in Fluid Power field, to act as both as a seal and as a physical component, for competition with metal retainers normally used for such purposes. However, since elastomer physical strength is lower than that of the metal, this valve will have to be limited as to the ultimate operating pressure it should serve. With urethane seal material exhibiting tensile properties of approximately 5,000 psi, and compressive strength of some compounds being quoted equally high, there is little doubt that these valves should outperform any counterpart employing undesirable metal to metal contact designs, and equal in pressure rating all existing poppet valves, except for size which in the design subject to this invention is considerably smaller for equal flow coefficient C_v.

Another factor for consideration in solenoid valves, is the fact that in the energy conserving tandem directional valve, the solenoid is used as a pilot unit for the purpose of shifting the stem only, without participation in fluid flow into and from the source to receiver, permitting valve design w/quite larger fluid passages and therefore larger flow characteristics, rarely found in poppet valves of such small size, capable of doing so large a work in terms of flow factor C_v, regardless of system pressures normally controlling the operating capabilities of solenoids directly involved in valve operation. Therefore, the tandem directional valve can employ as small a solenoid as an be produced regardless of valve size, ports or C_v specified for a specific valve, and irrespective of system pressures, within limits, of course. The reason for the ability to yield such a high flow coefficient is rather obvious, namely the valve seals do not have to cross fluid perpendicular ports during the shift and position change of the stem, and thus no limits are present in terms of annular sizes that control such flow coefficients enabling this valve-cylinder combination to provide extremely large flows to speed up cylinder operation beyond that attainable with other valve designs in existance while the tandem valve size is miniature as compared to other designs in existance with equivalent flows at high pressures.

In FIG. 1–*c* illustrating end of stem **26** of the longitudinal valve stem **24** in a position before entering valve exhaust bore **23** as shown in FIG. 1–*a* clearly illustrates ability available and proposed for increasing fluid exhaust means if desired. This can be accomplished by counterboring stem-end partway as shown by **32** and cross drilling holes **33** perpendicular to it & adjacent to the stem-end seal **30,** with as many holes **33** as it may deem to be desired, although the operation of this valve with an exhaust annular space **47**–*a* identified therein is insured without additional modification of the stem end **26** in miniature valve applications of this valve-cylinder combination of the invention.

FIG. **2** identifies cylinder with differential piston area.

As can be seen from FIG. **2,** cylinder **31,** with vent **50,** of differential diameter cylindrical body **51** having end closure **52** integral with a smaller cylindrical portion **53** of the cylinder closed end **54,** and enlarged cylindrical portion **55** at the other open cylinder end **56** which is threaded, an end closure **57** with seal **58** closing cylinder open end seal tight, and a central opening **59** therein for a rod seal **60,** is provided with a differential diameter piston **44** with smaller diameter **46** facing, and adjacent to closure **52** while larger diameter piston end **45** facing closure **57** terminates with piston rod **43** passing thru the central opening **59** with seal **60** and, in the illustrated case is in a retracted piston rod position with annulus **47** open to atmosphere via vent **50.** Port **61** leading to the smaller cylindrical portion **53** of cylinder **31** is provided for fluid communication from the fluid supply source under pressure as well as for fluid return via conduit **12** shown in FIGS. **1**–*a* and **1**–*b*. Port **20** serves for entering fluid exhausted from other cylinder end port **61** via conduits **12,** valve annular portions **8** & **15** and conduit **13** in energy conserving directional valve-cylinder combination with work required in both directions as is the case in most double acting cylinder application. It must be noted that the cylinder **31** described above is sound and quite self-explanatory regarding the differential diameter cylinder and piston principle, and its applicational variations in the field of fluid power control, with drastic improvements in the state of the art, but in practice it would not pay to produce such devices as FIG. **2** illustrates. It would be not only difficult but too costly to make a differential diameter closed end cylinder from metal competitively. Also the differential diameter piston and piston rod assembly of FIG. **2** is prohibitive costwise to be produced from one piece. Such devices in practice are borken down to separate parts such as cylinder, rod end and blind end for a cylinder assembly of existing practice, and to piston and piston rod made separately and then assembled to comprise a single unit normally involving piston rod threading into the piston and soldering such a joint, and then trueing it out because during soldering heat may distort parts, or otherwise making a cylinder assembly extremely costly, and in case under consideration, as shown in FIG. **2,** such a cylinder would not become rather very popular because of cost to produce it. Therefore we propose that the cylinder as identified in FIG. **2** be modified for adaptation to mass production, part of which is illustrated in FIG. **3.**

In FIG. **3,** the construction of differential piston-rod assembly is accentuated in a great detail with piston **200** representing small end, and piston **201** representing large end, with rod **202** providing a practical solution to the differential piston-rod assembly **203** of this invention. Such differential diameter piston-rod assembly may even be fabricated by the conventional means using steel or metal competitively, with rod section **204** serving as interconnecting link for differential diameter pistons. Thus, it has been demonstrated that the energy conserving valve-cylinder combination employing directional tandem valve accomplishes all stated objectives. Fabricating cylinder by conventional means or mass producing simplified designs from plastics by in-

jection molding or making cylinders from composite materials may be the best answer.

Some changes may be made in the construction and arrangements of the details without departing from the real spirit and purpose of this invention, disclosed and claimed herein.

What is claimed is:

1. An energy conserving directional valve-cylinder combination comprising:

a fluid motor including a cylinder, having one cylinder end blind including fluid supply and exhaust means provided therein, and another cylinder end open and adaptable to be closed partially by a rod end closure, said rod end closure including fluid supply and exhaust means provided therein and a central piston rod opening with a seal, said cylinder means including internal diameter tubular portions of large and small coaxial diameters separated by a shoulder substantially midway thereof, with said larger diameter portion initiating at the cylinder open end while said smaller diameter portion continuing inwardly from said shoulder until it meets said blind end provided with a closure, atmospheric vent means in said cylinder adjacent said shoulder,

a differential diameter piston means including coaxial piston rod attached thereto and protruding from said cylinder rod end closure, said piston means having an elongated smaller diameter piston at one end and a short larger diameter piston with said rod at the other end slidably received inside said cylinder means with said small piston entering said small diameter cylinder portion and said larger piston entering said large diameter cylinder portion and capable of axial movement in response to pressurized fluid supplied thereto by shuttling within cylinder confines controlled by said rod end closure at one piston rod extended position and said cylinder shoulder at the other piston rod retracted position, seals in said pistons,

means for actuating said fluid motor to perform work by said piston rod when coupled to a load during said position change of said differential diameter piston means inside said clyinder means, said actuation caused by said pressurized working fluid entering and leaving said fluid supply and exhaust means at each cylinder end alternatingly feeding said one cylinder end while simultaneously exhausting said other cylinder end, or vice versa as controlled by a directional valve closely coupled with said cylinder and capable of being selectively controlled between a first valve open position wherein fluid communication is permitted between a source of the pressurized working fluid and said cylinder blind end for pressurization of said small diameter piston with full pressure urging said piston rod extension under load, and a second valve closed position allowing energy extraction from fluid exhausted from said cylinder blind end by redirecting said working fluid in tandem from said blind end toward said cylinder open end provided with said rod end closure for pressurization of said larger diameter piston urging said piston rod retraction under load,

said energy conserving tandem directional valve comprising a multiported longitudinal valve housing having first and second ends interconnected by a bore extending therethrough, said bore having a first diameter portion adjacent said first end extending inwardly therefrom toward said second end, a second diameter portion adjacent said second end extending inwardly therefrom toward said first end and a third diameter portion interconnecting the innermost ends of said first and second diameters, said first and second diameter portions having larger diameters than said third diameter portion, including shoulders at interconnection of said diameters with a first shoulder facing said housing first end and a second shoulder facing said housing second end, said housing further including at least three perpendicular ports extending through said housing and communicating with said bore extending therethrough, one of said ports comprising a first fluid supply port communicating with said first diameter portion adjacent said first housing end and adaptable to be connected to said working fluid source, another of said ports comprising a second fluid port communicating with said third diameter portion and adaptable to be connected to said cylinder blind end, the remaining port comprising a third fluid port communicating with said second diameter portion adjacent said second housing end and adaptable to be connected to said fluid supply and exhaust means of said rod end closure covering said cylinder open end, said second bore end closed by an end cap provided with a central opening therethrough comprising a main valve exhaust port, said second and said third ports interconnected with said cylinder,

said first bore end receiving slidably an elongated stem with a piston at one end and a counterbored smaller diameter portion at the other end, said piston having a close sliding fit with the housing and having a seal received slidably inside said first diameter portion with piston head including an end face, a second seal in said stem received inside said first diameter portion and spaced along said stem from said piston adjacent said first shoulder with seal diameter less than the diameter of said piston but greater than said third diameter portion, a third seal in said stem having a diameter greater than said third diameter portion but less than said second diameter portion and located on a stem diameter portion received in said second diameter portion adjacent said second shoulder, a final seal on said opposite stem end adjacent said counterbored portion sized to permit close sliding fit inside said exhaust port of said end cap,

said stem being selectively shifted between a first position wherein said fluid communication is permitted between said first and second ports but precluded from entering said third port by said third seal firmly seated against said second shoulder while simultaneously allowing fluid communication between said third and said exhaust ports, and a second position wherein fluid communication is permitted between said second and third ports while having said second seal firmly seated against said first shoulder to preclude fluid communication between said first and second ports and also having said final seal engaged inside said main valve exhaust port to preclude fluid exhaust into the atmosphere, said stem further including a small fluid passage extending therethrough from said piston

face for selectively allowing fluid flow from said first diameter portion through said fluid passage and outwardly from said end face, said second port connected to said fluid supply and exhaust means of said cylinder blind end and said third port to said cylinder rod end closure supply and exhaust means,

a solenoid valve operator disposed at said first bore end of said housing, said operator having a plunger disposed generally coaxial with said stem and axially movable selectively in an operative relationship with solenoid energization between an open position spaced from said end face of said piston and defining a fluid cavity therebetween and a closed position in blocking engagement with said small passage at said end face, wherein when said plunger is in said closed position said stem is retained in said first position by fluid entering a first annulus formed between said stem and said first diameter portion provided with piston side, opposite said piston face end, exposed to said fluid with a force large enough to maintain said third seal firmly seated against said second shoulder when said stem is in said first position with said valve open to full pressure of the working fluid feeding said cylinder blind end via said second port to urge said piston rod into extended position while said main valve exhaust port is open to atmosphere, and wherein when said plunger is in said open position said stem is shifted to said second valve closed position by fluid entering said cavity through said passage in said piston end face and acting against said piston head exposed to said cavity with a force large enough to maintain said second seal firmly seated against said first shoulder while allowing pressurization of said cylinder open end provided with said rod end closure via said third port in communication with said second port through second and third annuluses formed between said second and third diameter portions and said stem by the fluid exhausted from said blind cylinder end to urge said piston rod into retracted position through the fluid action over said larger diameter piston,

said solenoid valve operator further including means for exhausting fluid from said cavity as said plunger is moved from said open toward said closed position, including spring biasing means for continuously exerting a biasing force on said plunger to force said plunger toward said closed position, whereby when said solenoid valve operator is deenergized said spring biasing means forces said plunger from said open into said closed position, energization of said solenoid causing said plunger to overcome said biasing force of said biasing means in moving from said closed to said open position.

2. A valve-cylinder combination as in claim **1** wherein said stem seals include tubular sections of elastomer rings.

3. A valve-cylinder combination as defined in claim **1** wherein said conservation of energy includes the utilization of tandem flow of pressurized fluid through said tandem directional valve, initiating at said fluid supply first port receiving pressurized fluid from the source and continuing into said second port to serve said cylinder bind end, and returning to said second fluid port to enter said third fluid port to serve said cylinder open end provided with said rod end closure, and again returning to said third fluid port for final exhaust into the atmosphere via said main valve exhaust port, said tandem fluid flow enabling extraction of useful pressure energy in compliance with the equilibrium energy equation expressed by the relationship $P_1V_1 = P_2V_2$, said relationship enabling the operation of said valve-cylinder combination with resultant significant conservation of energy, said relationship effective when combined with piston areas at each cylinder end.

4. A valve-cylinder combination as in claim **1** wherein said differential diameter piston means includes a plain rod with said small diameter piston of short length at one end and said larger diameter piston of short length positioned a distance away from said small diameter piston along said rod in accordance with cylinder stroke requirements, with said rod extending therethrough.

5. A device as in claim **1** wherein when said stem, subjected to the working fluid pressure, is forced to change said position from said first valve open position to said second valve closed position, said working fluid pressure end thrust force is absorbed by said stem seals, materially extending the service life of said tandem directional valve, said second and said third stem seals absorbing all impact forces developed during said stem position change.

6. A device as in claim **1** wherein said solenoid operator is used as a pilot unit solely for purpose of shifting said stem without direct participation in the flow of the working fluid through said valve permitting the utilization of considerably larger fluid flow passages therethrough, and permitting the use of as small a solenoid as available irrespective of the magnitude of the working fluid pressure.

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