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(54) **Fluid operated actuator including a deformable sealing member**

(57) A fluid operated actuator (200) is provided. The fluid operated actuator (200) includes a housing (201) and a piston (202) movable within the housing (201). The fluid operated actuator (200) further includes a piston rod

(203) coupled to the piston (202). A deformable sealing member (206) is also provided. The deformable sealing member (206) is coupled to the piston rod (203) at a first end and coupled to the housing (201) at a second end.

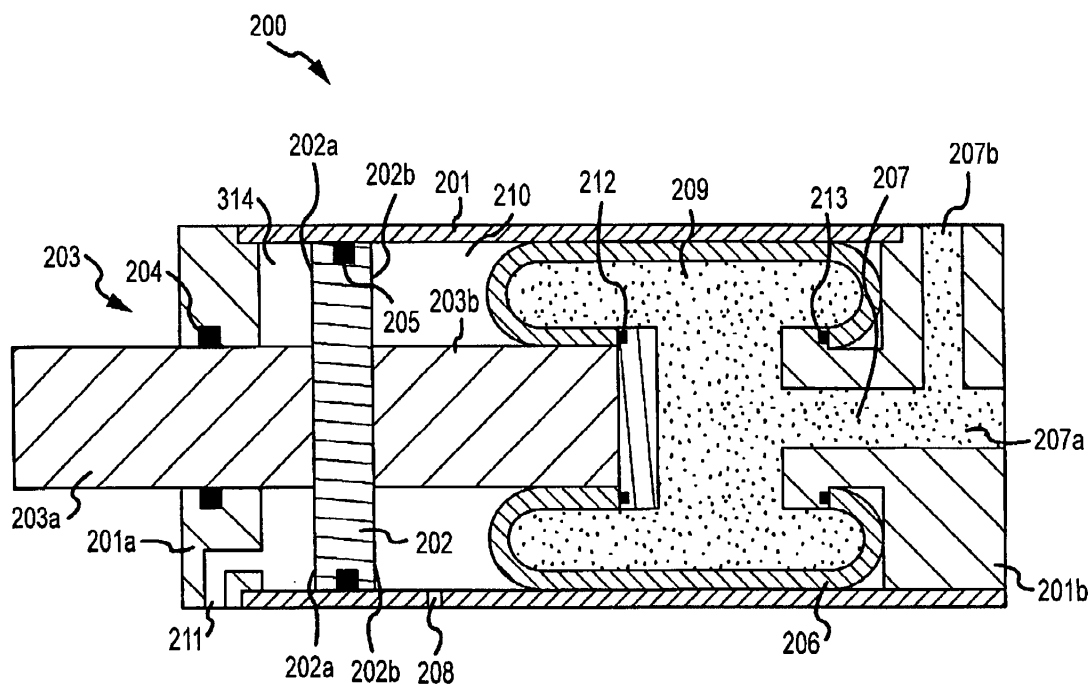


FIG. 3

Description

TECHNICAL FIELD

[0001] The present invention relates to, fluid operated actuators, and more particularly, to a fluid operated actuator including a deformable sealing member.

BACKGROUND OF THE INVENTION

[0002] Fluid operated actuators are generally known in the art, and have received great success, in part, because of their wide range of applicability. One example of a fluid operated actuator is a piston positioned in a cylinder. The piston typically separates the cylinder into two fluid chambers. The piston may be attached to a working carriage extending through a sealed portion of the cylinder wall. Another example comprises a rod attached to the piston and extending through at least one end of the cylinder. In some situations, the piston rod may extend through both ends of the cylinder. In each of the above-mentioned examples, a pressurized fluid can be introduced into the cylinder to act on the piston to move the piston in one direction while fluid on the second side of the piston is exhausted to the environment or supplied to an external component. Therefore, as the piston is moving, the fluid pressure is converted into a mechanical force.

[0003] Alternatively, mechanical force acting on the piston rod or the carriage can be converted into a fluid pressure to be applied to some external component. The pressurized fluid used in combination with the fluid operated actuator may comprise a gas, such as air, or a liquid, such as hydraulic fluid, for example. In some situations, the fluid operated actuator may use both gas and liquid. For example, one of the fluid chambers of the cylinder may receive a gas while the other fluid chamber may receive a liquid. This type of arrangement may be desirable where the gas may be exhausted to the atmosphere, yet the liquid may be recycled. In many situations where one of the fluid chambers is pressurized with a gas and the other fluid chamber is pressurized with a liquid, a deformable sealing member, such as a bellows or a diaphragm is used to separate the two fluids. An example of such an arrangement can be seen in hydropneumatic actuators, such as used for vehicle suspensions. While deformable sealing members are not necessary in all circumstances, the deformable sealing member can substantially reduce the fluid cross-contamination that typically occurs when the fluid is separated by only the piston seals. This is because as the piston moves within the cylinder of fluid operated actuators without deformable sealing members, some of the liquid may be dragged along with the seals and left on the cylinder wall thereby contaminating the gas. Likewise, the gas often leaks into the liquid side of the piston thereby contaminating the liquid. Both situations are undesirable.

[0004] FIG. 1 shows a prior art fluid operated actuator

10. The prior art fluid operated actuator 10 includes a housing 11, a piston 12 movable within the housing 11, a piston rod 13 coupled to the piston 12 and extending from the housing 11. The housing 11 includes a sealing member 21 that forms a substantially fluid-tight seal between the housing 11 and the piston rod 13. The prior art fluid operated actuator 10 also includes a deformable seal 14 in the form of a bellows coupled to the piston 12. The piston 12 and the bellows 14 separate the housing 11 into a first fluid chamber 15 and a second fluid chamber 16. The first fluid chamber 15 is shown in fluid communication with a first port 17 while the second fluid chamber 16 is shown in fluid communication with a second port 18. The prior art fluid operated actuator 10 may receive pressurized air at the first port 17 and pressurized hydraulic fluid at the second port 18, for example. Therefore, the piston 12 and the bellows 14 can separate the pressurized air from the hydraulic fluid.

[0005] As shown in FIG. 1, the piston 12 does not form a fluid-tight seal with the cylinder 11. Rather, the piston 12 forms a substantially fluid-tight seal with the bellows 14 using a sealing member 19. The sealing member 19 therefore is provided to form a substantially fluid tight seal between the piston 12 and the bellows 14. Likewise, the bellows 14 forms a substantially fluid-tight seal with the housing 11 using a sealing member 20.

[0006] While the sealing members 19, 20 are designed to maintain fluid separation between the air provided at port 17 and the hydraulic fluid provided at port 18, each sealing member 19, 20 comprises a potential leak point. In other words, the bellows 14 includes two potential leak points. Both of the sealing members 19, 20 are subjected to the pressurized air as well as the pressurized hydraulic fluid. Consequently, the air may leak directly into the hydraulic fluid thereby contaminating the hydraulic fluid by changing the compressibility of the hydraulic fluid, which can disadvantageously affect the external device in fluid communication with the port 18. This is obviously undesirable; however, it is often difficult to prevent. Furthermore, the pressurized hydraulic fluid can leak into the first fluid chamber 15, thereby contaminating the pressurized air. Those skilled in the art will readily appreciate that the difficulty in preventing cross-contamination increases as the pressure of the fluids increases. The prior art fluid operated actuator, therefore does not provide ideal or adequate fluid separation.

[0007] Another problem with the prior art actuator 10 is that the piston 12 does not contact the housing 11, rather only the piston rod 13 is contacting the housing 11. Therefore, during times of pressure fluctuation, the stability of the piston assembly can be jeopardized. Therefore, the piston assembly may not move smoothly as it extends from and retracts into the housing 11.

[0008] The present invention overcomes the above-mentioned problem and an advance in the art is achieved. The present invention provides a fluid operated actuator including a deformable sealing member provided in one of the fluid chambers. While the deformable sealing

member contains one of the pressurized fluids, it is not exposed directly to both high-pressure fluids. Therefore, the risk of cross contamination between the pressurized fluids is substantially reduced.

SUMMARY OF THE INVENTION

[0009] A fluid operated actuator is provided according to an embodiment of the invention. According to an embodiment of the invention, the fluid operated actuator comprises a housing and a piston movable within the housing. According to an embodiment of the invention, the fluid operated actuator further comprises a piston rod coupled to the piston. According to an embodiment of the invention, the fluid operated actuator further comprises a deformable sealing member coupled to the piston rod at a first end and coupled to the housing at a second end.

[0010] A method for forming a fluid operated actuator is provided according to an embodiment of the invention. The method comprises a step of positioning a piston movably within a housing. The method further comprises a step of coupling a piston rod to the piston. According to an embodiment of the invention, the method further comprises steps of coupling a first end of a deformable sealing member to the piston rod and coupling a second end of the deformable sealing member to the housing.

ASPECTS

[0011] According to an aspect of the invention, a fluid operated actuator comprises:

- a housing;
- a piston movable within the housing;
- a piston rod coupled to the piston; and
- a deformable sealing member coupled to the piston rod at a first end and coupled to the housing at a second end.

[0012] Preferably, the fluid operated actuator further comprises a first fluid chamber defined by the deformable sealing member, the housing, and the piston rod, in fluid communication with a first fluid port.

[0013] Preferably, the fluid operated actuator further comprises a second fluid port in fluid communication with a first side of the piston.

[0014] Preferably, the fluid operated actuator further comprises a vent port in fluid communication with a second side of the piston.

[0015] Preferably, the fluid operated actuator further comprises a second fluid chamber defined by the second side of the piston, the housing, and the deformable sealing member, the second fluid chamber being in fluid communication with the vent port.

[0016] Preferably, the piston rod comprises a first portion extending from a first side of the piston and a second portion extending from a second side of the piston, and

wherein the deformable sealing member is coupled to the second portion of the piston rod.

[0017] Preferably, the first portion of the piston rod extends through the housing.

[0018] According to another aspect of the invention, a method for forming a fluid operated actuator comprises steps of:

- positioning a piston movably within a housing;
- coupling a piston rod to the piston;
- coupling a first end of a deformable sealing member to the piston rod; and
- coupling a second end of the deformable sealing member to the housing.

[0019] Preferably, the method further comprises a step of defining a first fluid chamber in fluid communication with a first fluid port with the deformable sealing member, the housing, and the piston rod.

[0020] Preferably, the method further comprises a step of forming a second fluid port in fluid communication with a first side of the piston.

[0021] Preferably, the method further comprises a step of forming a vent port in fluid communication with a second side of the piston.

[0022] Preferably, the method further comprises a step of defining a second fluid chamber by the second side of the piston, the housing, and the deformable sealing member, wherein the second fluid chamber is in fluid communication with the vent port.

[0023] Preferably, the piston rod comprises a first portion extending from a first side of the piston and a second portion extending from a second side of the piston, wherein the step of coupling a first end of the deformable sealing member to the piston rod comprises a step of coupling the first end of the deformable sealing member to the second portion of the piston rod.

[0024] Preferably, the method further comprises a step of extending the first portion of the piston rod through the housing.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025]

FIG. 1 shows a prior art fluid operated actuator.

FIG. 2 shows a fluid operated actuator according to an embodiment of the invention.

FIG. 3 shows the fluid operated actuator according to another embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0026] FIGS. 2-3 and the following description depict specific examples to teach those skilled in the art how to make and use the best mode of the invention. For the purpose of teaching inventive principles, some conventional aspects have been simplified or omitted. Those

skilled in the art will appreciate variations from these examples that fall within the scope of the invention. Those skilled in the art will appreciate that the features described below can be combined in various ways to form multiple variations of the invention. As a result, the invention is not limited to the specific examples described below, but only by the claims and their equivalents.

[0027] FIG. 2 shows a cross-sectional view of a fluid operated actuator 200 according to an embodiment of the invention. According to an embodiment of the invention, the fluid operated actuator 200 comprises a housing 201, a piston 202 movable within the housing 201, and a piston rod 203 coupled to the piston 202. According to the embodiment shown, the piston rod 203 comprises a first portion 203a extending from a first side 202a of the piston 202 and a second portion 203b extending from a second side 202b of the piston 202. According to the embodiment shown, the first portion 203a of the piston rod 203 also extends through the housing 201. More particularly, the housing 201 includes an end cap 201a and the first portion 203a of the piston rod 203 extends through the end cap 201a. The piston 202 and the piston rod 203 may be formed from independent components. The piston 202 and the piston rod 203 may then be coupled according to well-known techniques such as welding, brazing, bonding, adhesives, mechanical fasteners, etc. Alternatively, the piston 202 and the piston rod 203 may comprise a single integrally formed component, for example, the components may be integrally molded.

[0028] According to an embodiment of the invention, the fluid operated actuator 200 comprises a first sealing member 204. The first sealing member 204 is shown coupled to the housing 201 and substantially surrounding the first portion 203a of the piston rod 203. According to an embodiment of the invention, the first sealing member 204 forms a substantially fluid-tight seal between the housing 201 and the first portion 203a of the piston rod 203. More specifically, the first sealing member 204 can be provided in a first end cap 201a of the housing 201. Therefore, the first sealing member 204 can form a substantially fluid-tight seal between the end cap 201a and the first portion 203a of the piston rod 203. The first sealing member 204 can advantageously prevent pressurized fluid entering a fluid port 211 from escaping between the end cap 201a of the housing 201 and the first portion 203a of the piston rod 203.

[0029] According to an embodiment of the invention, the piston 202 comprises a sealing member 205. The sealing member 205 can be provided to form a substantially fluid-tight seal between the piston 202 and the housing 201. According to an embodiment of the invention, the sealing member 205 can slide along the interior wall of the housing 201 as the piston 202 moves within the housing 201. The sealing member 205 may comprise any suitable sealing member, such as an O-ring, a K-ring, etc. According to an embodiment of the invention, the sealing member 205 can advantageously prevent fluid that enters the fluid operated actuator 200 through the

port 211 from reaching the second side 202b of the piston 202. Furthermore, because the piston 202 slides along the inside wall of the housing 201, movement of the piston 202 is stabilized compared to the prior art fluid operated actuator 10 that relies solely on the piston rod 13 to stabilize movement of the piston 12.

[0030] According to an embodiment of the invention, the fluid operated actuator 200 further comprises a deformable sealing member 206. The deformable sealing member 206 may be in the form of a bellows, a diaphragm, a hose roll, or the like. According to an embodiment of the invention, the deformable sealing member 206 can be coupled to two portions of the fluid operated actuator 200 that are movable with respect to one another. Therefore, as the two portions move with respect to each other, the deformable sealing member 206 can elastically deform.

[0031] According to an embodiment of the invention, the deformable sealing member 206 can be coupled to the piston rod 203. In the embodiment shown, the deformable sealing member 206 is coupled to the second portion 203b of the piston rod 203 at a first end and coupled to the housing 201 at a second end. However, it should be appreciated that in other embodiments, the deformable sealing member 206 may be coupled to the first portion 203a of the piston rod 203 that extends through the housing 201. In the embodiment shown, the deformable sealing member 206 is coupled to an end cap 201b of the housing 201. The deformable sealing member 206 may be coupled to the piston rod 203 and the end cap 201b using any suitable form of coupling, such as adhesives, brazing, bonding, welding, mechanical fasteners, etc. The particular type of coupling may depend upon the materials used for the components and should in no way limit the scope of the present invention.

[0032] In the embodiment shown, the fluid operated actuator 200 is shown with sealing points 212 and 213, which provide substantially fluid-tight seals between the deformable sealing member 206 and the second portion 203b of the piston rod and the end cap 201b, respectively. The sealing points 212, 213 may comprise independent sealing members, such as O-rings or alternatively, the deformable sealing member 206 may be coupled directly to the associated components without requiring a separate sealing element. With the deformable member 206 coupled to the piston rod 203 rather than being coupled directly to the piston 202 as in the prior art, the piston 202 is able to slide along the inside wall of the housing 201. As can be appreciated, the deformable sealing member 206 can move and elastically deform in response to movement of the piston 202 and thus, the piston rod 203. However, because the deformable sealing member 206 does not slide between moving parts, the deformable sealing member 206 is less susceptible to wear due to friction.

[0033] According to an embodiment of the invention, the deformable sealing member 206 can define a first fluid chamber 209. In the embodiment shown, the first

fluid chamber 209 is defined at least in part by the deformable member 206, the second portion 203a of the piston rod 203 and the end cap 201b. According to an embodiment of the invention, the first fluid chamber 209 can be in fluid communication with the first fluid port 207. According to an embodiment of the invention, the first fluid port 207 can be in fluid communication with a pressurized fluid source (not shown). In some embodiments, the pressurized fluid source may provide the fluid operated actuator with a substantially incompressible fluid, such as hydraulic fluid, for example. In other embodiments, the first fluid port 207 may be in fluid communication with a compressible fluid, such as air. In either situation, the first fluid chamber 209, and thus, the deformable sealing members 206 retain the pressurized fluid received by the first fluid port 207 and substantially prevent the pressurized fluid from reaching a second fluid chamber 210.

[0034] According to an embodiment of the invention, the second fluid chamber 210 is defined at least in part by the deformable sealing member 206, the housing 201, and the second side 202b of the piston 202. According to the embodiment of the invention shown in FIG. 2, the second portion 203b of the piston rod 203 extends through the second fluid chamber 210. According to an embodiment of the invention, the second chamber 210 is in fluid communication with a vent port 208. The vent port 208 may be open to atmosphere or may be in communication with a fluid line (not shown) used to recycle fluid that may reach the vent port 208. Consequently, in the unlikely event that pressurized fluid from the first fluid chamber 209 leaks through one or both of the sealing points 212, 213 where the deformable sealing member 206 is coupled to the second portion 203a of the piston rod 203 and the end cap 201 b, respectively, the fluid can simply be exhausted from the fluid operated actuator 200 through the vent port 208. Therefore, the vent port 208 can prevent pressure from building up in the second fluid chamber 210. The vent port 208 can also prevent a vacuum from forming and resisting movement of the piston 202 within the housing 201.

[0035] FIG. 3 shows a cross-sectional view of the fluid operated actuator 200 according to another embodiment of the invention. In the embodiment shown in FIG. 3, the piston 202 and the piston rod 203 have moved to the right from the position shown in FIG. 2. The movement may be due to the introduction of pressurized fluid into the fluid port 211. Alternatively, the movement may be due to an external force being applied to the first portion 203a of the piston rod 203.

[0036] As can be seen in FIG. 3, with the piston 202 moved to the right, a third fluid chamber 314 is now visible. The third fluid chamber 314 is defined at least in part by the first side 202a of the piston 202, the housing 201, and the end cap 201a. The third fluid chamber 314 is in fluid communication with the second fluid port 211. According to an embodiment of the invention, the second fluid port 211 may be in fluid communication with a pres-

surized fluid source (not shown). The second fluid port 211 may be supplied with a compressible fluid, such as air, for example. Alternatively, the second fluid port 211 may be supplied with a substantially incompressible fluid, such as hydraulic fluid, for example.

[0037] As can be appreciated, the pressurized fluid supplied to the second fluid port 211 acts on the piston 202 to bias the piston 202, and thus, the piston rod 203 in a first direction (to the right as shown in the figures). Conversely, the pressurized fluid supplied to the first fluid port 207 acts on the second portion 203a of the piston rod 203 and the deformable sealing member 206 to bias the piston rod 203 and thus, the piston 202 in a second direction (to the left as shown in the figures).

[0038] While prior art fluid operated actuators including a deformable sealing member utilize the deformable sealing member to separate the two pressurized fluid supplies, i.e., both pressurized fluids are in contact with the deformable sealing member, according to an embodiment of the invention, only one of the pressurized fluid supplies is designed to be in direct contact with the deformable sealing member 206. As can be appreciated, the second fluid chamber 210 provides a "buffer" chamber. In other words, if pressurized fluid from the fluid port 211 leaks past the sealing member 205 of the piston 202, the pressurized fluid is exhausted through the vent port 208 without accumulating to an appreciable pressure. Likewise, if pressurized fluid from the fluid port 207 leaks from the first fluid chamber 209, the fluid is likewise exhausted through the vent port 208. Advantageously, the risk of cross-contamination between the two pressurized fluid sources is substantially reduced compared to the prior art fluid operated actuators. The reduced risk of cross-contamination between the two pressurized fluid sources is due to the second fluid chamber 210, which is formed due to the deformable sealing member 206 being coupled to the piston rod 203 rather than the piston 202, and is located between the first and third fluid chambers 209, 314.

[0039] In use, pressurized fluid can be supplied to the second fluid port 211 to move the piston 202 and the piston rod 203 to the right as shown in FIG. 3. The pressurized fluid in the first fluid chamber 209 may be partially exhausted through the fluid port 207 during this movement. As can be appreciated any fluid in the second fluid chamber 210 can be exhausted through the vent port 208 so that movement of the piston 202 is not restricted by fluid in the second fluid chamber 210. As discussed above, in some embodiments, the pressurized fluid supplied to the fluid port 211 may comprise a compressible fluid, such as air, for example. In some embodiments, movement of the piston 202 and the piston rod 203 in the first direction may not require the substantially high force that can be delivered using an incompressible fluid, such as hydraulic fluid, for example.

[0040] According to an embodiment of the invention, with the piston 202 and the piston rod 203 moved in the first direction, pressurized fluid can be supplied to the

first fluid port 207 in order to actuate the piston 202 and thus, the piston rod 203 in the second direction, i.e., to the left as shown in the figures. During this step, the second port 211 may be opened to exhaust to allow the third fluid chamber 314 to exhaust. According to an embodiment of the invention, the pressurized fluid supplied to the first fluid port 207 comprises a substantially incompressible fluid, such as hydraulic fluid, for example. The pressurized fluid supplied to the first fluid port 207 may come from a primary port 207a or a secondary port 207b. For example, in some situations, the primary port 207a may be supplied with the pressurized fluid at a first pressure while the secondary port 207b is supplied with the pressurized fluid at a second pressure. The primary and secondary ports 207a, 207b may include appropriate valves (not shown) to prevent fluid from one of the ports exhausting to the other. An example of such a situation would be in a welding gun operation where the fluid operated actuator is actuated with a first force during a first stroke and actuated with a second force during a second stroke. For example, the pressurized fluid may be supplied to the primary port 207a at a pressure of approximately 6 bar (87 psi) to actuate the piston 202 from a first position to a second position. During this time, a check valve or other type of valve may prevent the fluid from the primary port 207a from exhausting through the secondary port 207b. During a second stage of actuating the piston 202, the primary port 207a may be closed off using a suitable valve and the pressurized fluid may be supplied via the secondary port 207b at a second pressure, for example 60 bar (870 psi), to actuate the piston 202 from the second position to a third position. The particular pressures used in the present example should in no way limit the scope of the present invention.

[0041] According to an embodiment of the invention, the unique sealing arrangement provided by the deformable sealing member 206 allows the fluid operated actuator 200 to receive pressures up to and exceeding 60 bar (870 psi) without the fluid leaking into the third fluid chamber 314, i.e., on the first side 202a of the piston 202. As can be appreciated, the deformable sealing member 206 can contact the wall of the housing 201. Therefore, the housing 201 can help support the deformable sealing member 206 when the deformable sealing member 206 is exposed to the high pressure. Further, with the deformable sealing member 206 containing the pressurized fluid from the first fluid port 207, the housing 201 can be formed from a lighter material, such as aluminum. Prior art fluid operated actuators that receive a hydraulic fluid are typically formed from steel due to the increased strength requirements.

[0042] As explained above, in the unlikely event that some of the pressurized fluid in the first fluid chamber 209 does leak into the second fluid chamber 210, the fluid can easily be exhausted out of the fluid operated actuator 200 via the vent port 208. Advantageously, the pressurized fluid in the first fluid chamber 209, which may comprise an incompressible fluid such as hydraulic fluid,

will not contaminate the pressurized fluid in the third fluid chamber 314, which may comprise a compressible fluid such as air.

[0043] It should be appreciated that while the description above describes a single deformable sealing member 206, the present invention should not be limited to a single deformable sealing member. Rather, according to another embodiment of the invention, the fluid operated actuator 200 may include more than one deformable sealing member. For example, a deformable sealing member may be provided on each side of the piston 202.

[0044] The present invention as described above provides an improved fluid operated actuator 200. The improved fluid operated actuator 200 advantageously includes a deformable sealing member 206 that is coupled to the piston rod 203 rather than the piston 202 as in prior art configurations. This unique coupling creates a second fluid chamber 210 that separates the two pressurized fluid chambers 209, 314. Consequently, if pressurized fluid leaks out of one of the pressurized fluid chambers, the leaked fluid does not contaminate the other fluid chamber. Rather, the leaked fluid can be vented out of the fluid operated actuator 200 through a vent port 208. The fluid operated actuator 200 of the present invention can therefore operate under high fluid pressures while reducing the chances of fluid cross-contamination compared to prior art fluid operated actuators that include deformable sealing members.

[0045] The detailed descriptions of the above embodiments are not exhaustive descriptions of all embodiments contemplated by the inventors to be within the scope of the invention. Indeed, persons skilled in the art will recognize that certain elements of the above-described embodiments may variously be combined or eliminated to create further embodiments, and such further embodiments fall within the scope and teachings of the invention. It will also be apparent to those of ordinary skill in the art that the above-described embodiments may be combined in whole or in part to create additional embodiments within the scope and teachings of the invention.

[0046] Thus, although specific embodiments of, and examples for, the invention are described herein for illustrative purposes, various equivalent modifications are possible within the scope of the invention, as those skilled in the relevant art will recognize. The teachings provided herein can be applied to other fluid operated actuators, and not just to the embodiments described above and shown in the accompanying figures. Accordingly, the scope of the invention should be determined from the following claims.

Claims

1. A fluid operated actuator (200), comprising:
a housing (201);

- a piston (202) movable within the housing (201);
a piston rod (203) coupled to the piston (202);
and
a deformable sealing member (206) coupled to
the piston rod (203) at a first end and coupled
to the housing (201) at a second end.
2. The fluid operated actuator (200) of claim 1, further comprising a first fluid chamber (209) defined by the deformable sealing member (206), the housing (201), and the piston rod (203), in fluid communication with a first fluid port (207).
 3. The fluid operated actuator (200) of claim 1, further comprising a second fluid port (211) in fluid communication with a first side (202a) of the piston (202).
 4. The fluid operated actuator (200) of claim 1, further comprising a vent port (208) in fluid communication with a second side (202b) of the piston (202).
 5. The fluid operated actuator (200) of claim 4, further comprising a second fluid chamber (210) defined by the second side (202b) of the piston (202), the housing (201), and the deformable sealing member (206), the second fluid chamber (210) being in fluid communication with the vent port (208).
 6. The fluid operated actuator (200) of claim 1, wherein the piston rod (203) comprises a first portion (203a) extending from a first side (202a) of the piston (202) and a second portion (203b) extending from a second side (202b) of the piston (202), and wherein the deformable sealing member (206) is coupled to the second portion (203b) of the piston rod (203).
 7. The fluid operated actuator (200) of claim 6, wherein the first portion (203a) of the piston rod (203) extends through the housing (201).
 8. A method for forming a fluid operated actuator, comprising steps of:

positioning a piston movably within a housing;
coupling a piston rod to the piston;
coupling a first end of a deformable sealing member to the piston rod; and
coupling a second end of the deformable sealing member to the housing.
 9. The method of claim 8, further comprising a step of defining a first fluid chamber in fluid communication with a first fluid port with the deformable sealing member, the housing, and the piston rod.
 10. The method of claim 8, further comprising a step of forming a second fluid port in fluid communication with a first side of the piston.
 11. The method of claim 8, further comprising a step of forming a vent port in fluid communication with a second side of the piston.
 12. The method of claim 11, further comprising a step of defining a second fluid chamber by the second side of the piston, the housing, and the deformable sealing member, wherein the second fluid chamber is in fluid communication with the vent port.
 13. The method of claim 8, wherein the piston rod comprises a first portion extending from a first side of the piston and a second portion extending from a second side of the piston, wherein the step of coupling a first end of the deformable sealing member to the piston rod comprises a step of coupling the first end of the deformable sealing member to the second portion of the piston rod.
 14. The method of claim 13, further comprising a step of extending the first portion of the piston rod through the housing.

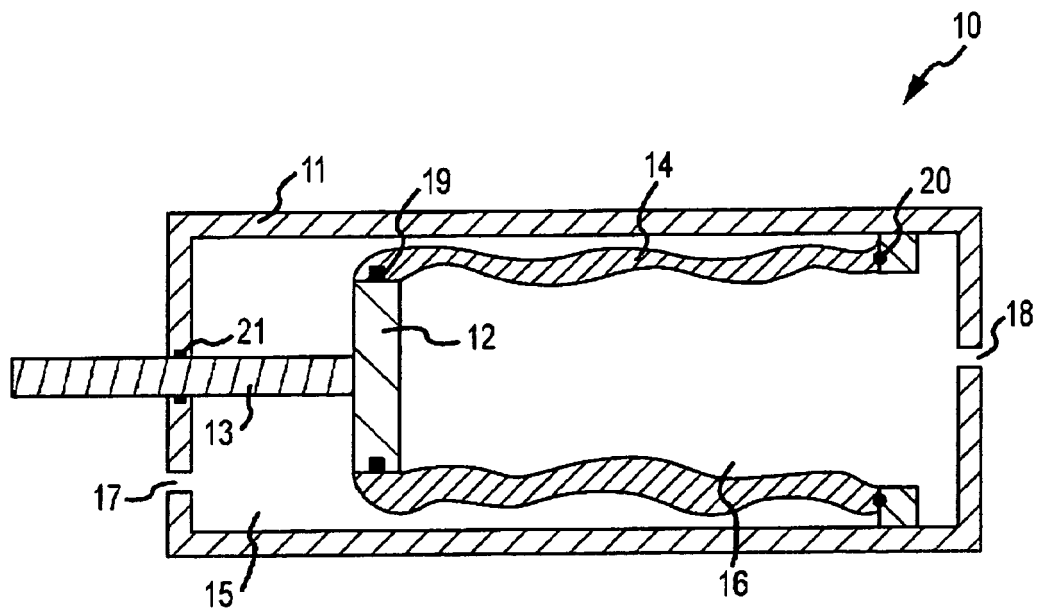


FIG. 1
(PRIOR ART)

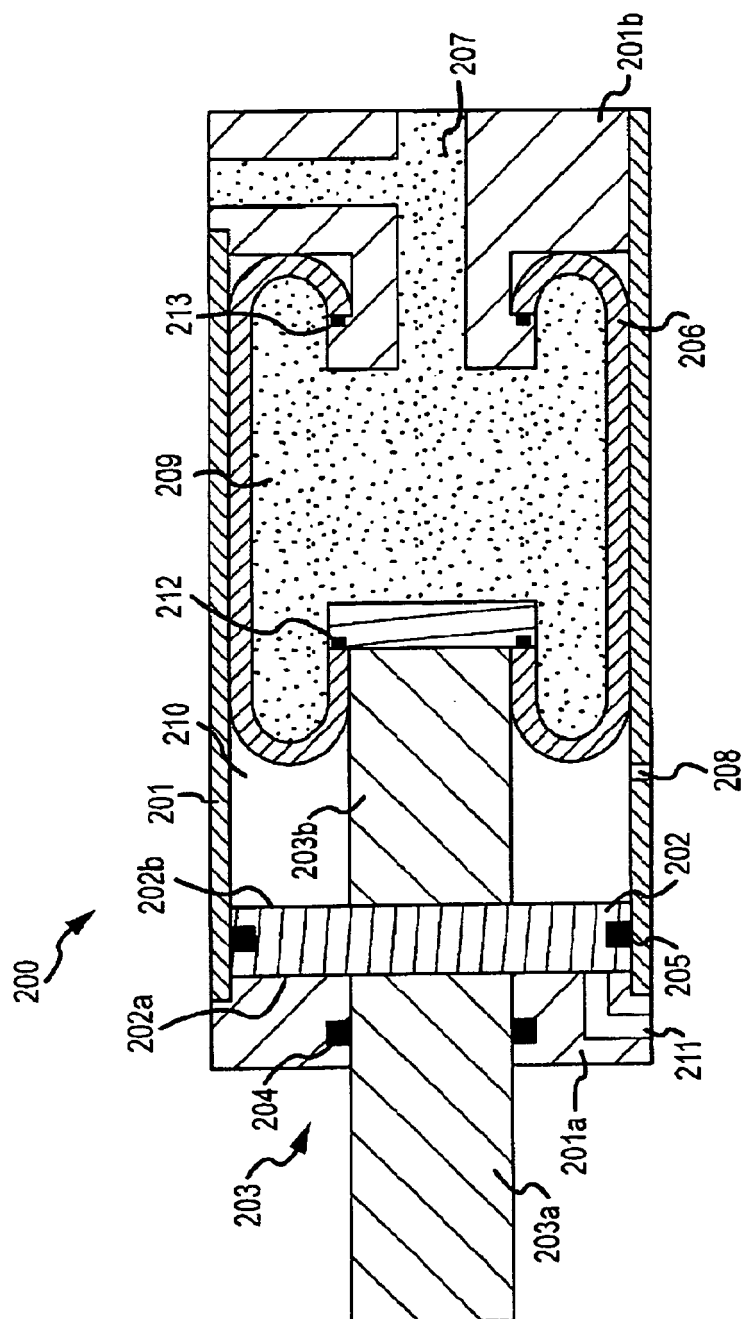


FIG. 2

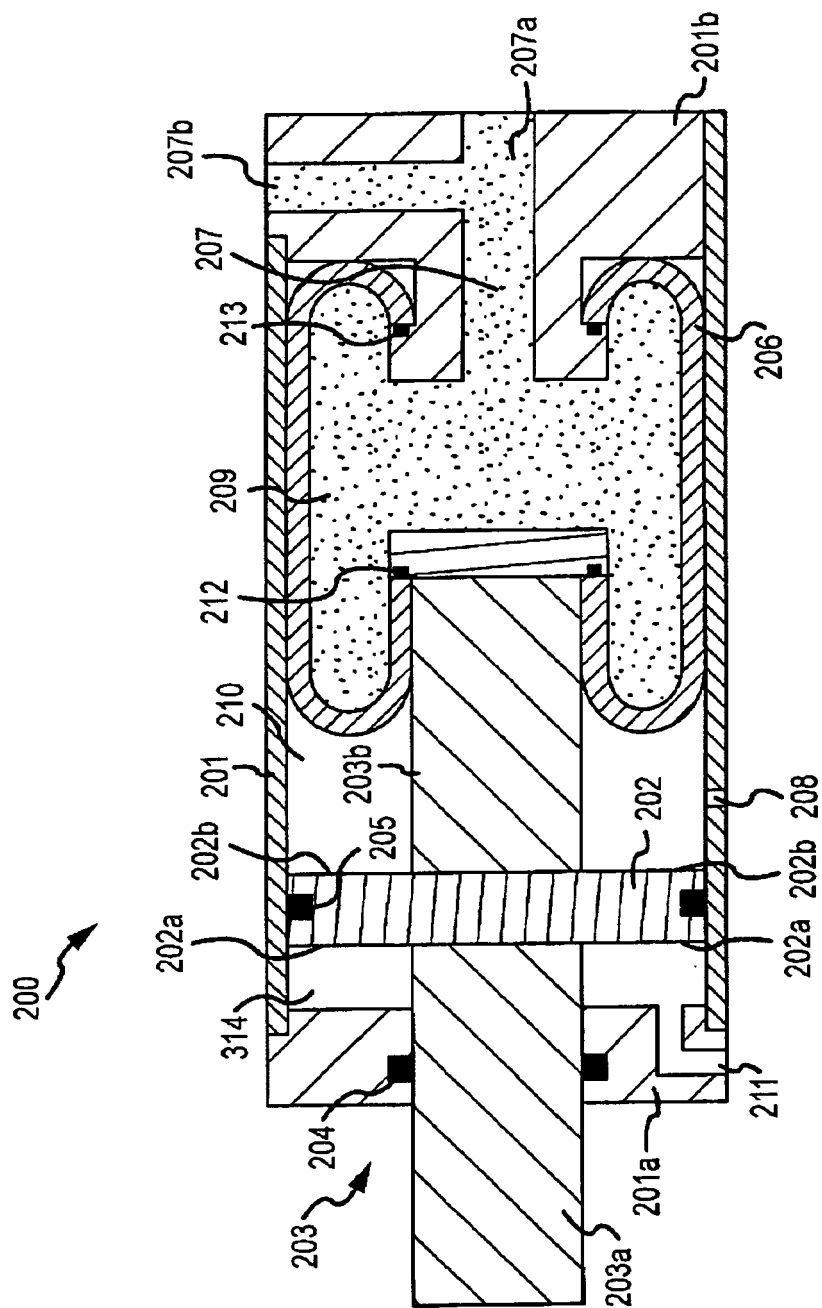


FIG. 3