US 20110116957A2

(19) **United States**

(12) **Patent Application Publication**

**SCEKIC**

(10) **Pub. No.: US 2011/0116957 A2**

(43) **Pub. Date: May 19, 2011**

**REPUBLICATION**

(54) **RECIPROCATING PUMP**

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(21) Appl. No.: **12/685,490**

(22) Filed: **Jan. 11, 2010**

**Prior Publication Data**

(65) US 2010/0303655 A1 Dec. 2, 2010

**Related U.S. Application Data**

(60) Provisional application No. 61/144367, filed on Jan. 13, 2009.

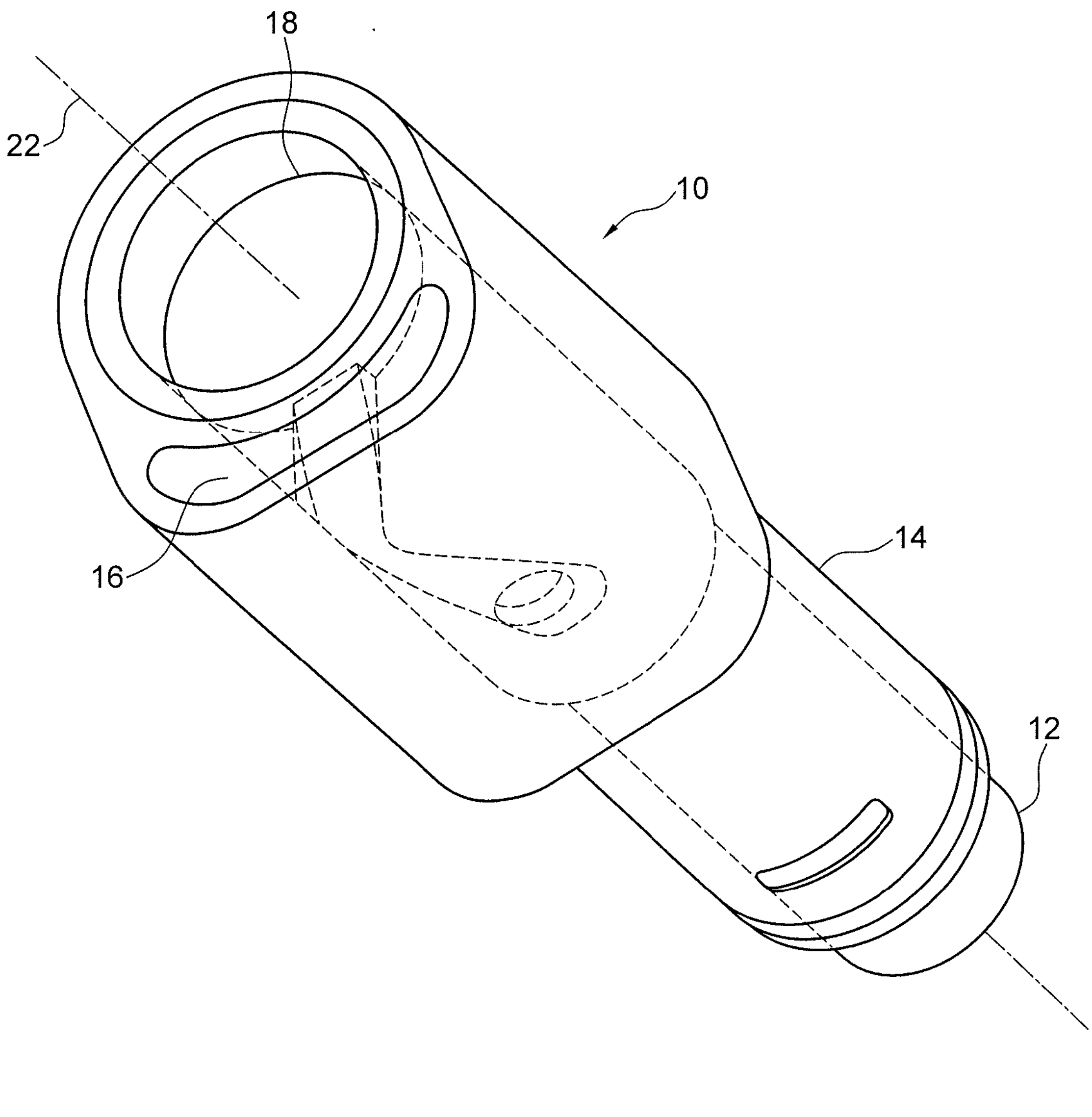
**Publication Classification**

(51) **Int. Cl.**
***F04B 7/06*** (2006.01)
***F04B 39/10*** (2006.01)

(52) **U.S. Cl.** .......... **417/490**

(57) **ABSTRACT**

A reciprocating pump including a sleeve comprising a first flow path element and a plunger receivable in the sleeve is provided. The plunger includes a fluid contact face and second flow path element in fluid communication with the fluid contact face. The sleeve and the fluid contact face define a compression chamber comprising an inlet and an outlet. The sleeve and the plunger are moveable relative to one another for adjusting overlap between the first flow path element and the second flow path element for diverting flow of fluid from the compression chamber and out of the second flow path element during a discharge stroke to control flow of fluid pumped out of the outlet.



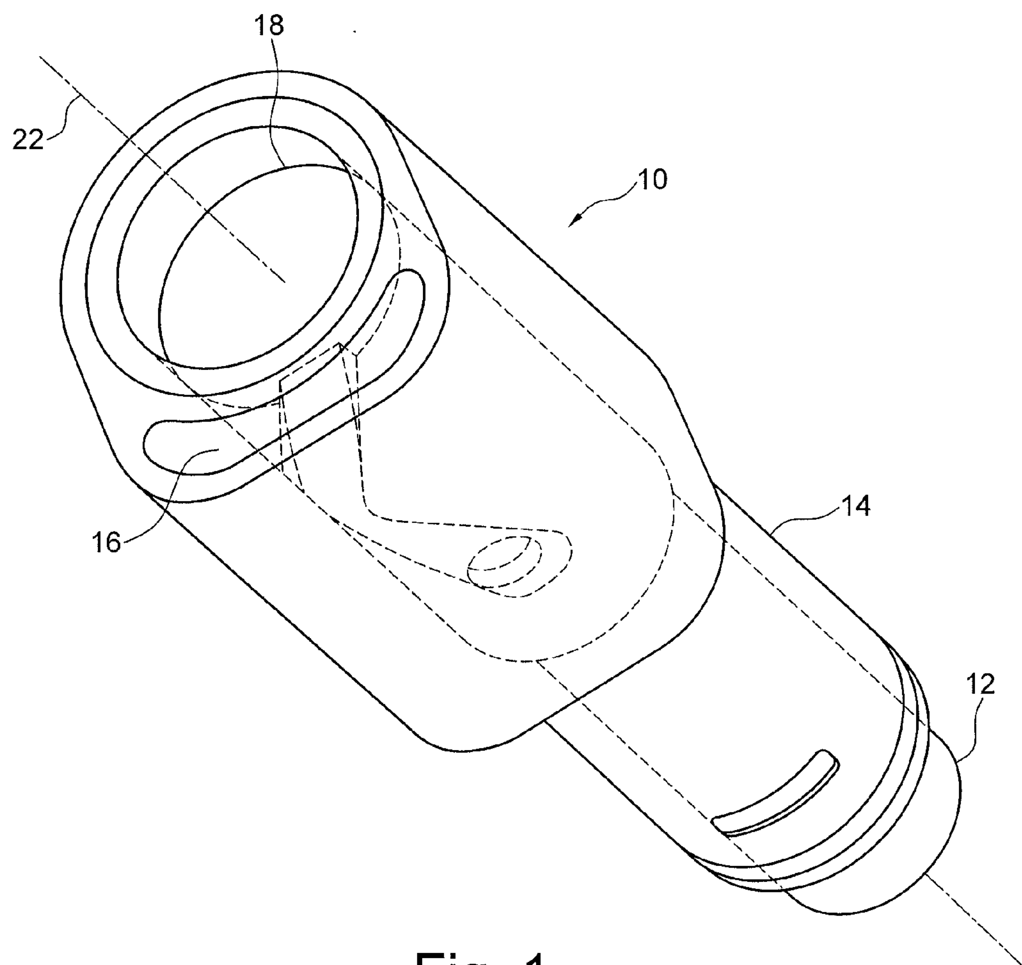



Fig. 1

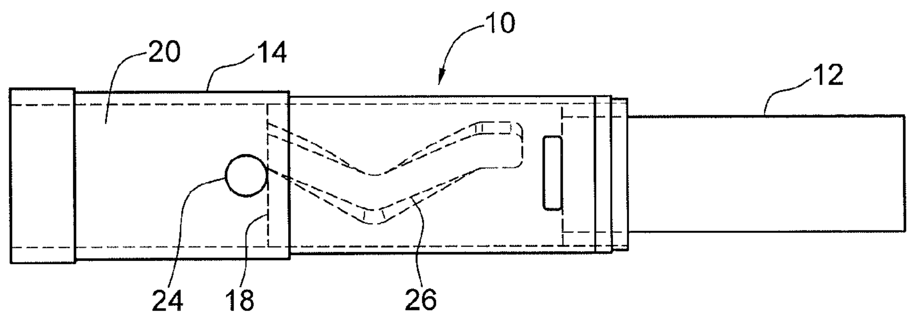



Fig. 2A

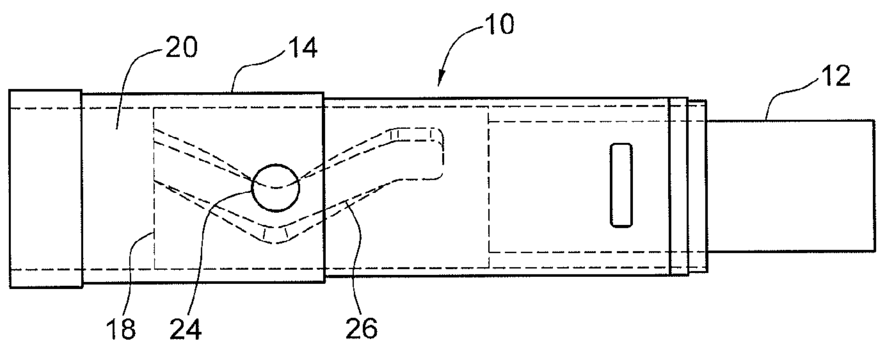



Fig. 2B

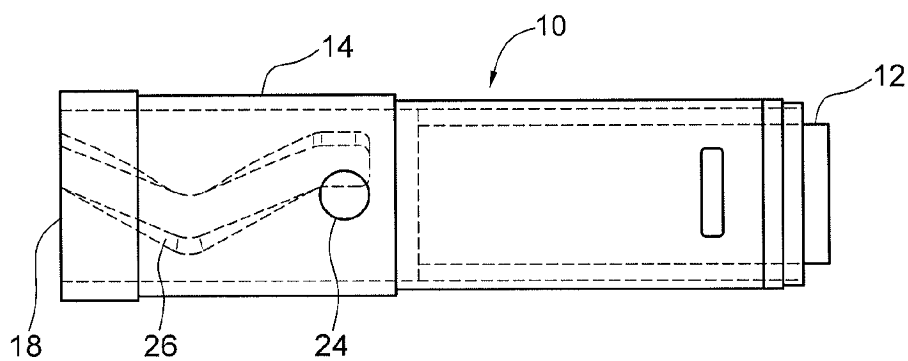



Fig. 2C

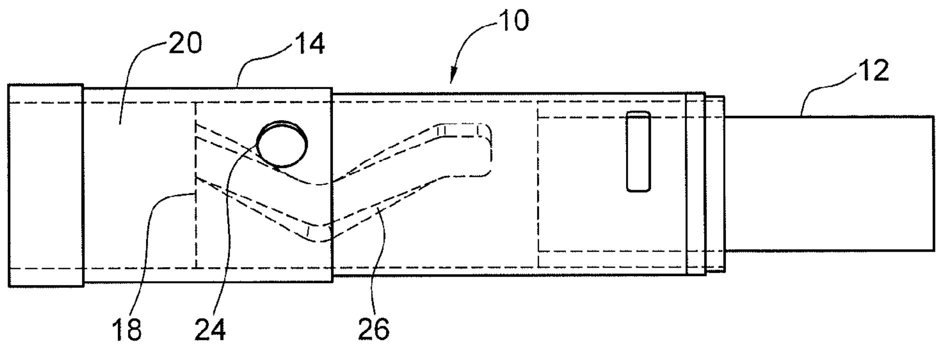



Fig. 3A

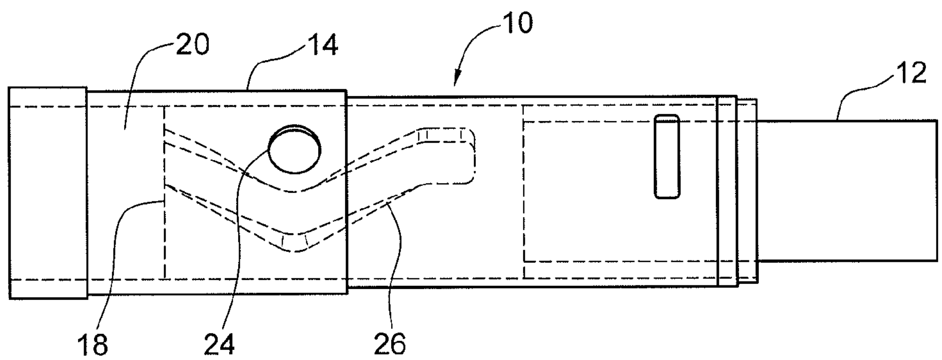



Fig. 3B

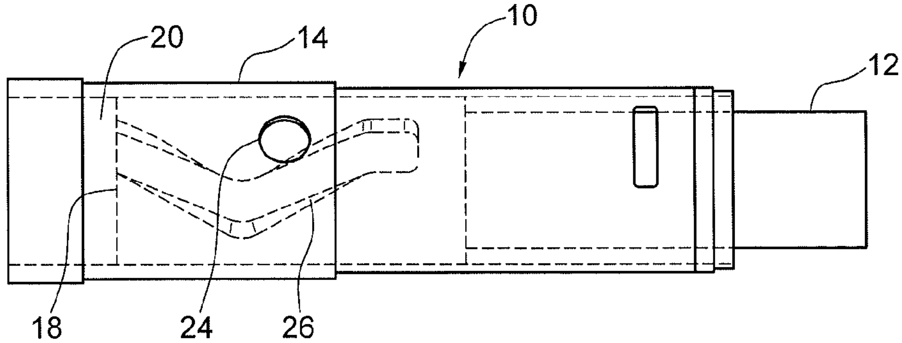



Fig. 3C

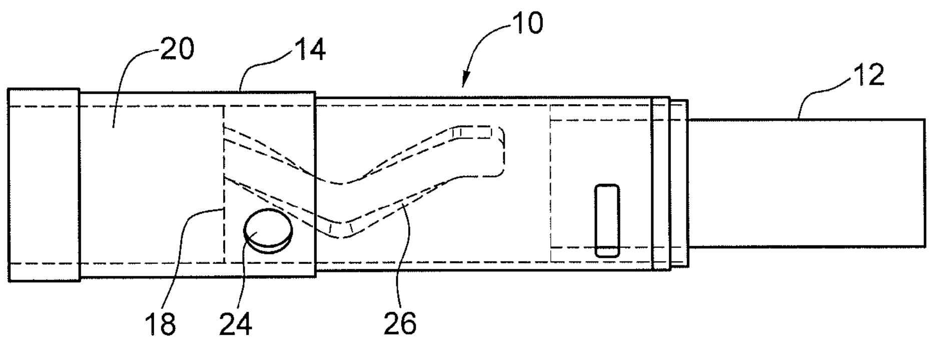



Fig. 4A

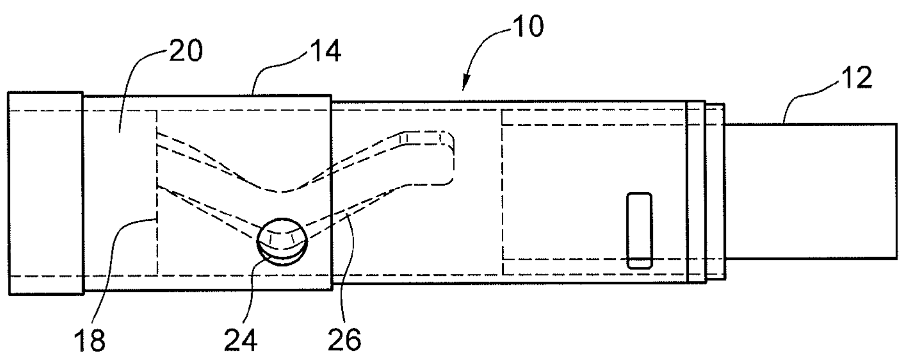



Fig. 4B

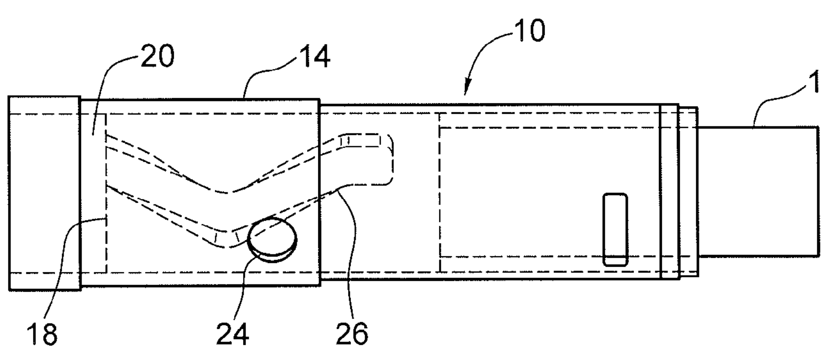



Fig. 4C

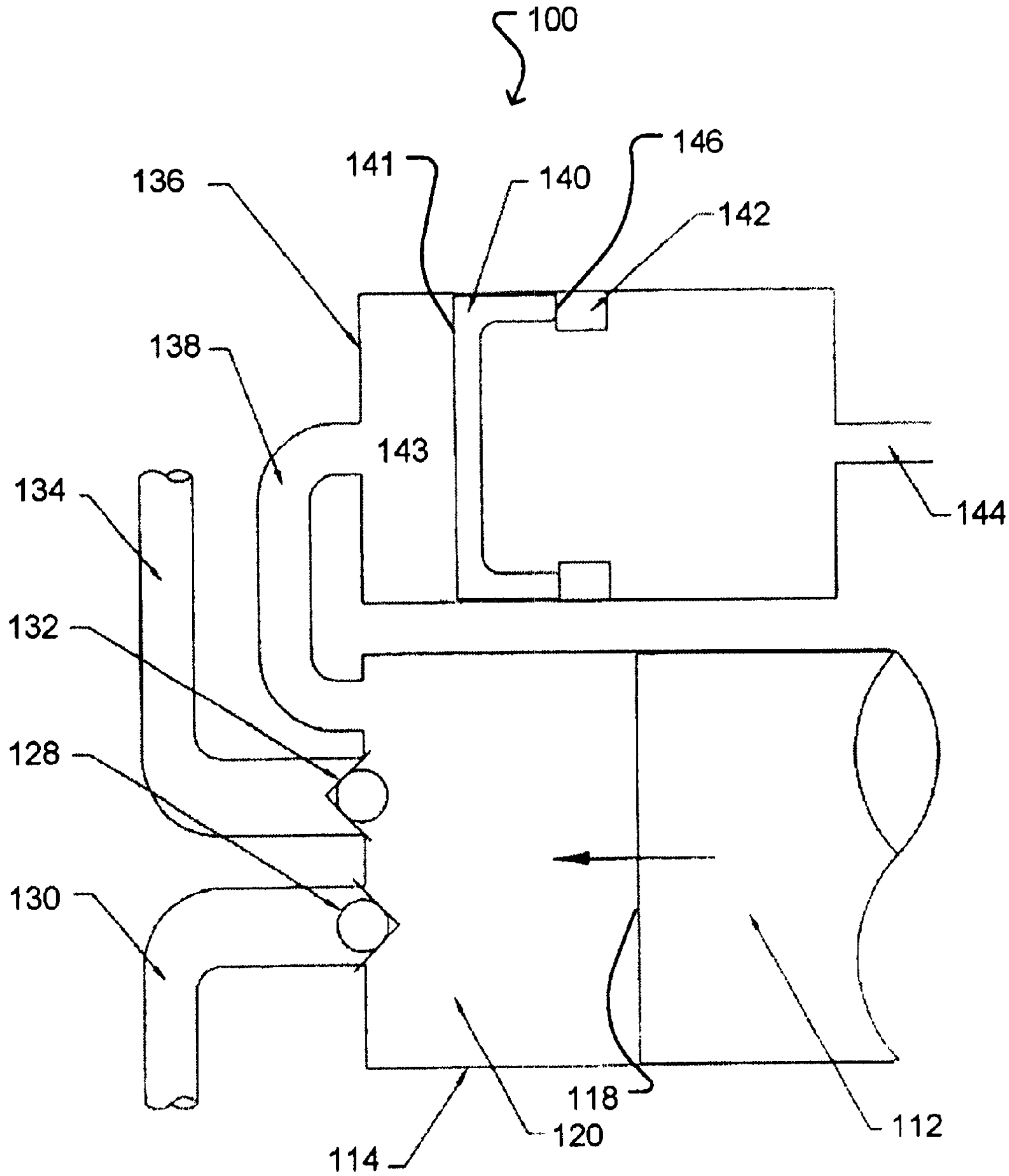

100
136
141
140
146
142
138
143
134
144
132
128
130
118
112
114
120

Fig. 5

# RECIPROCATING PUMP

## TECHNICAL FIELD

[0001] This invention relates to reciprocating pumps, and more particularly reciprocating pumps having flow control for use for example in mud-pumping and frac-pumping applications in the oil-and-gas industry and in reciprocating gas compressors.

## BACKGROUND

[0002] Reciprocating pumps are commonly used in applications where high volumes of fluid need to be pumped at high pressures. Highest efficiency reciprocating pumps are most commonly driven by a crank or cam mechanism. Since any given crank or cam mechanism provides for a constant stroke of the plunger, currently two methods are usually used for controlling volumetric flow of these pumps:

[0003] changing the liner/plunger size (liners and plungers of smaller diameter provide for less flow per stroke of the pump and vice versa),

[0004] changing the speed of the pump (slowing down the pump will result in less "strokes per minute" which will result in less flow of fluid and vice versa).

[0005] Both methods have serious limitations. Changing the liners and plungers is labour-intensive and requires skilled labour, and the pump must be taken out of service while the change is being done, resulting in "down time" of the pump. Controlling the speed may be practical within a limited range if a diesel or gas engine is being used as a prime mover. However, if an electric motor is used as a prime mover, very expensive and inefficient speed controls need to be used, such as VFD or DC controllers. In order to achieve an appropriate match between pumping requirements and capabilities of the engines used as prime movers, expensive, multispeed transmissions are often used, especially in frac-pumping applications where such transmissions are often 6, 7 or even 8-speed units. Mud-pumping applications often use 2-speed transmissions. In reciprocating gas compressor applications, various factors influence the discharged flow of gas, including temperature, humidity and the age of the engine.

[0006] Accordingly, there is a need for efficient and inexpensive apparatus and methods for controlling the volumetric flow of fluid discharged from reciprocating pumps.

## SUMMARY

[0007] The present invention provides for "active" stroke control of reciprocating pumps. Some or all of a plunger stroke can be rendered ineffective by diverting fluid away from the compression chamber of a pump. Controlling the amount of this ineffective portion of the stroke is used to control the actual volume of fluid being pumped out of a pump and downstream of a discharge valve.

[0008] One aspect of the invention provides a reciprocating pump having a sleeve and a plunger receivable in the sleeve. The sleeve has a first flow path element. The plunger has a fluid contact face and a second flow path element in fluid communication with the fluid contact face. The sleeve and the fluid contact face define a compression chamber having an inlet and an outlet. The sleeve and the plunger are moveable relative to one another for adjusting overlap between the first flow path element and the second flow path element for diverting flow of fluid from the compression chamber and out of the second flow path element during a discharge stroke to control flow of fluid pumped out of the outlet.

[0009] Another aspect of the invention provides a reciprocating pump having a sleeve and a plunger receivable in the sleeve. The sleeve has a sidewall with a control hole. The plunger has a fluid contact face and a helical channel in fluid communication with the fluid contact face. The sleeve and the fluid contact face define a compression chamber with an inlet and an outlet. The sleeve and the plunger are rotatable relative to one another about a common longitudinal axis to adjust the overlap between the control hole and the helical channel for diverting flow of fluid from the compression chamber and out of the control hole during a discharge stroke to control flow of fluid pumped out of the outlet.

[0010] A further aspect of the invention provides a reciprocating pump having a sleeve and a plunger receivable in the sleeve. The sleeve has a sidewall with a helical channel. The plunger has a fluid contact face, a sidewall, and a bore in fluid communication with the fluid contact face. A first end of the bore defines a control hole formed in the sidewall. The sleeve and the fluid contact face define a compression chamber with an inlet and an outlet. The sleeve and the plunger are rotatable relative to one another about a common longitudinal axis to adjust the overlap between the control hole and the channel for diverting flow of fluid from the compression chamber and out of the control hole during a discharge stroke to control flow of fluid pumped out of the outlet.

[0011] Another aspect of the invention provides a reciprocating pump having a sleeve and a plunger receivable in the sleeve. The plunger has a fluid contact face, and the sleeve and the fluid contact face define a compression chamber with an inlet and an outlet. The pump also includes an accumulator in fluid communication with the compression chamber for diverting flow of fluid away from the compression chamber during a discharge stroke to control flow of fluid pumped out of the output. The accumulator has a housing, a control element slidingly receivable in the housing, a moveable stop, and a force means biasing the control element away from the moveable stop. The control element has a fluid contact face, and the fluid contact face and the housing defining an accumulation chamber. The moveable stop is configured to adjustably define a maximum volume of fluid diverted to the accumulation chamber by restricting movement of the control element.

[0012] A further aspect of the invention provides a method of controlling flow of fluid pumped by a reciprocating pump during a discharge stroke. The method includes the steps of:

[0013] (a) providing a reciprocating pump with a sleeve and a plunger receivable in the sleeve, the sleeve having a first flow path element, the plunger having a face and a second flow path element in fluid communication with the face, wherein the sleeve and the face define a compression chamber comprising an inlet and an outlet, and the sleeve and the plunger are rotatable along a common axis relative to one another; and

(b) rotatably adjusting overlap between the first flow path element and the second flow path element to divert flow of fluid from the compression chamber and out of the control hole.

[0014] Another aspect of the invention provides a method of controlling flow of fluid pumped by a reciprocating pump during a discharge stroke. The method includes the steps of:

[0015] (a) providing a reciprocating pump with a compression chamber and an accumulator in fluid communication with the compression chamber, the accumulator having a housing; a control element slidingly receivable in the housing, the control element having a fluid contact face, the fluid contact face and the housing defining an accumulation chamber; and a moveable stop configured to restrict movement of the control element to define a maximum volume of the accumulation chamber; and

(b) moving the moveable stop to adjust the maximum volume of the accumulation chamber to control a volume of fluid diverted from the compression chamber to the accumulation chamber.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0016] In drawings which show non-limiting embodiments of the invention:

[0017] FIG. **1** is a perspective see-through view of one embodiment according to the present invention;

[0018] FIGS. **2**A to **2**C are side see-through views of the embodiment shown in FIG. **1** at sequential stages of a discharge stroke from bottom dead centre to top dead centre;

[0019] FIGS. **3**A to **3**C are side see-through views of the embodiment shown in FIG. **1** at sequential stages of a discharge stroke from top dead centre to top dead centre;

[0020] FIGS. **4**A to **4**C are side see-through views of the embodiment shown in FIG. **1** at sequential stages of a discharge stroke from top dead centre to top dead centre; and

[0021] FIG. **5** is a schematic view of one embodiment according to the present invention.

## LIST OF REFERENCE CHARACTERS

[0022] **10** reciprocating pump

[0023] **12** plunger

[0024] **14** sleeve

[0025] **16** overflow chamber

[0026] **18** fluid contact face of plunger **12**

[0027] **20** compression chamber

[0028] **22** axis

[0029] **24** control hole

[0030] **26** channel

[0031] **100** reciprocating pump

[0032] **112** plunger

[0033] **114** sleeve

[0034] **118** fluid contact face of plunger **112**

[0035] **120** compression chamber

[0036] **128** discharge valve

[0037] **130** discharge manifold

[0038] **132** suction valve

[0039] **134** suction manifold

[0040] **136** hydraulic cylinder

[0041] **138** fluid port

[0042] **140** piston

[0043] **141** fluid contact face of piston **140**

[0044] **142** stop

[0045] **143** accumulation chamber

[0046] **144** air pressure source

## DETAILED DESCRIPTION

[0047] It will be appreciated that numerous specific details are set forth in order to provide a thorough understanding of the exemplary embodiments described herein. However, it will be understood by those of ordinary skill in the art that the embodiments described herein may be practiced without these specific details. In other instances, well-known methods, procedures and components have not been described in detail so as not to obscure the embodiments described herein. Furthermore, this description is not to be considered as limiting the scope of the embodiments described herein in any way, but rather as merely describing the implementation of the various embodiments described herein.

[0048] FIG. **1** shows a plunger **12**, sleeve **14** and overflow chamber **16** of the "wet end" of a reciprocating pump **10** according to one embodiment of the present invention.

[0049] The "power end" of plunger **12**, shown at the bottom right of FIG. **1**, is connected to the cross-head of the pump (not shown) which is, in turn, connected to the crankshaft via a connecting rod (not shown). Rotary motion of the crankshaft is converted into a linearly oscillating motion of plunger **12**. Plunger **12** can move between top dead centre ("TDC", or the position furthest away from the crankshaft where the crank-throw and connecting rod are in line) and Bottom Dead Centre ("BDC", or the position nearest to the crankshaft where the crank-throw and connecting rod are in line). Reciprocating pump **10** may also be a cam-driven pump. Movement from TDC to BDC is referred to as the suction stroke; movement from BDC to TDC is referred to as the discharge stroke. Reference herein to the term "stroke" of the plunger will be to the discharge stroke unless otherwise stated.

[0050] The "wet end" of plunger **12**, shown at the upper left of FIG. **1**, and in particular fluid contact face **18** is in contact with the fluid being pumped and, with the surrounding walls of sleeve **14**, define compression chamber **20**. Reference herein to the term "fluid" includes liquids, including suspensions such as drilling mud, and gases.

[0051] A typical reciprocating pump also comprises a pump-head assembly which incorporates inlets or suction valves and outlets or discharge valves (not shown), each allowing flow of fluid in one direction only (either into the sleeve or out of it).

[0052] Reference is now made to FIGS. **2**A to **2**C. Sleeve **14** is rotated about axis **22** such that a first flow path element, such as control hole **24** formed in a sidewall of sleeve **14**, overlaps with a second flow path element, such as channel **26** formed in a sidewall of plunger **12**, throughout the discharge stroke. Channel **26** may be helical. Reference herein to the term "channel" includes any formation on and/or in the plunger through which fluid can flow including cutouts, grooves, bores and the like. Fluid can thus be diverted from compression chamber **20** through helical channel **26**, through control hole **24**, into overflow chamber **16** and back to a fluid port (not shown) upstream of the suction valve of pump **10**. As this diverted fluid flow is uninterrupted during the discharge stroke, pump **10** runs completely unloaded, that is, no fluid is actually pumped.

[**0053**] Reference is now made to FIGS. **3**A to **3**C. Sleeve **14** is rotated about axis **22** such that control hole **24** overlaps with helical channel **26** only at the beginning and the end of the discharge stroke, allowing the path of flow to be diverted only for these portions of the discharge stroke. Near the middle of the stroke, control hole **24** faces a solid wall of plunger **12** thus interrupting the diverted flow path and forcing the fluid to exit compression chamber **20** through the discharge valve. Pump **10** thus runs loaded only at the middle of the discharge stroke.

[**0054**] Reference is now made to FIGS. **4**A to **4**C. Sleeve **14** is rotated about axis **22** such that control hole **24** overlaps with helical channel **26** only near the middle of the stroke. Near the beginning and the end of the stroke, control hole **24** faces the solid wall of plunger **12** thus interrupting the diverted flow path and forcing the fluid to exit compression chamber **20** through the discharge valve. Pump **10** thus runs loaded only at the beginning and end of the discharge stroke.

[**0055**] Sleeve **14** can also be rotated about axis **22** such that control hole **24** never overlaps with helical channel **26**. In this position (not shown), flow of fluid cannot be diverted through control hole **24**, forcing all of the fluid to exit compression chamber **20** through the discharge valve. Pump **10** thus runs fully loaded throughout the discharge stroke.

[**0056**] Control of the diverted fluid flow can be achieved through a number of combinations of channels and control holes. In some embodiments a plurality of channels and/or control holes may be provided. In some embodiments, the channel may be provided on the sleeve and the control hole may be defined by a first end of a bore formed in the plunger (with another end of the bore formed at the fluid contact face of the plunger). In some embodiments, the plunger (instead of the sleeve) may be rotated to effect flow control. In some embodiments, both the plunger and the sleeve may be rotated to effect flow control. The channels and control holes may be any suitable size or shape that, in overlapping cooperation during a discharge stroke, permit incremental, graduated or step-wise control of fluid flow.

[**0057**] FIG. **5** shows a reciprocating pump **100** according to another embodiment of the invention. Many components shown, notably plunger **112**, sleeve **114**, fluid contact face **118**, and compression chamber **120** are similar in all aspects to equivalents components of reciprocating pump **10**. Outlet or discharge valve **128**, discharge manifold **130**, inlet or suction valve **132** and suction manifold **134** are also shown. An accumulator, in the form of a hydraulic cylinder **136** in this particular embodiment, is connected to compression chamber **120** by the means of a fluid port **138**. A control element, in the form of a piston **140** in this particular embodiment, can slide dynamically inside hydraulic cylinder **136**, and pushed back and forth by pressure from fluid from compression chamber **120**, towards stop **142**, and by pressure from a force means **144** biasing piston **140** away from stop **142**. As would be appreciated by a person skilled in the art, in other embodiments the stop may be located on the opposite side (i.e., fluid port side) of the control element, such that fluid from the compression chamber pushes the control element away from the stop, and pressure from the force means pushes the control element towards the stop. A fluid contact face **141** of piston **140** and hydraulic cylinder **136** define an accumulation chamber **143**.

[**0058**] Force means **144** may be any suitable source of pressure for biasing piston **140** away from stop **142**. In the illustrated embodiment, force means **144** is a source of air pressure. In other embodiments, force means **144** may, for example, be spring (e.g. a compression spring), a deformable resilient member, or the like.

[**0059**] Stop **142** is moveable and can be adjusted to restrict the travel of piston **140** during the pump operation, thereby defining a maximum volume of fluid that can be diverted to hydraulic cylinder **136** from compression chamber **120**. Stop **142** may be any suitable mechanical, electrical, or magnetic means for restricting the travel of piston **140**. In the illustrated embodiment, stop **142** is an annular ring disposed in the hydraulic cylinder **136**, wherein the travel of piston **140** is restricted by abutment of a bearing surface **146** of piston **140** against the annular ring.

[**0060**] Before plunger **112** starts its discharge stroke, piston **140** will be moved away from stop **142** against the head of hydraulic cylinder **136**, driven by air pressure from air pressure source **144**. Suction pressure of the fluid is typically around 25 psi.

[**0061**] At start of discharge stroke of plunger **112**, piston **140** will start moving towards stop **142** by the pressure of fluid from compression chamber **120**. Since pressure in discharge valve **128** is considerably higher than the air pressure from air pressure source **144** behind piston **140**, no fluid will pass through discharge valve **128** until piston **140** hits stop **142**. Once piston **140** hits stop **142**, pressure will start increasing in compression chamber **120** and usable flow of fluid will start and last until the end of the discharge stroke of plunger **112**.

[**0062**] Once plunger **112** starts its suction stroke, piston **140** will start moving away from stop **142** driven by air pressure from air pressure source **144**. Only once piston **140** hits the end of its stroke opposite stop **142**, suction valve will open **132** and "new" fluid will enter compression chamber **120**.

[**0063**] Flow control is thus effected by controlling the position of stop **142**; moving it closer to fluid port **138** of hydraulic cylinder **136** will reduce the volume of accumulation chamber **143** and thus increase the effective pump flow; moving it away from fluid port **138** of hydraulic cylinder **136** will increase the volume of accumulation chamber **143** and thus reducing the effective pump flow.

[**0064**] The pumps described above are particularly suitable for use in high pressure and/or high volume applications such as mud-pumping and frac-pumping applications in the oil-and-gas industry, as well as in reciprocating gas compressor applications. Reciprocating pump **100** is particularly suitable for reciprocating gas compressor applications.

**1**. A reciprocating pump comprising:

(a) a sleeve comprising a first flow path element;

(b) a plunger receivable in the sleeve, the plunger comprising:

i. a fluid contact face and

ii. a second flow path element in fluid communication with the fluid contact face;

wherein the sleeve and the fluid contact face define a compression chamber comprising an inlet and an outlet;

and wherein the sleeve and the plunger are moveable relative to one another for adjusting overlap between the first flow path element and the second flow path element for diverting flow of fluid from the compression chamber and out of the second flow path element during a discharge stroke to control flow of fluid pumped out of the outlet.

**2**. A reciprocating pump according to claim 1, wherein the sleeve comprises a sidewall, and the first flow path element comprises a control hole formed in the sidewall of the sleeve.

**3**. A reciprocating pump according to claim 2, wherein the plunger comprises a sidewall, and the second flow path element comprises a channel formed in the sidewall of the plunger.

**4**. A reciprocating pump according to claim 1, wherein the sleeve comprises a sidewall, and the first flow path element comprises a channel formed in the sidewall of the sleeve.

**5**. A reciprocating pump according to claim 4, wherein the plunger comprises a sidewall, the second flow path element comprises a bore formed in the plunger, and a first end of the bore defines a control hole formed in the sidewall of the plunger.

**6**. A reciprocating pump according to claim 5, wherein the sleeve and the plunger are rotatable relative to one another about a common axis for adjusting the overlap between the control hole and the channel.

**7**. A reciprocating pump according to claim 6, wherein the overlap is adjustable between a range of no overlap, whereby no fluid is diverted away from the compression chamber, and complete overlap whereby fluid is completely diverted away from the compression chamber.

**8**. A reciprocating pump according to claim 7, wherein the sleeve is rotatable.

**9**. A reciprocating pump according to claim 7, wherein the plunger is rotatable.

**10**. A reciprocating pump according to claim 9, wherein the channel is helical.

**11**. A reciprocating pump according to claim 3, wherein the control hole is in fluid communication with an overflow chamber.

**12**. A reciprocating pump according to claim 6, wherein the channel is in fluid communication with an overflow chamber.

**13**. A reciprocating pump according to claim 12, wherein the overflow chamber is in fluid communication with a fluid port upstream of the inlet.

**14**. A reciprocating pump according to claim 13, wherein the sleeve comprises a hollow cylinder with an opening for receiving the plunger.

**15**. A reciprocating pump according to claim 14, wherein the plunger comprises a cylinder.

**16**. A reciprocating pump according to claim 15, wherein the control hole is round.

**17**. A reciprocating pump comprising:

(a) a sleeve comprising a sidewall, the sidewall comprising a control hole;

(b) a plunger receivable in the sleeve, the plunger comprising:

i. a fluid contact face and

ii. a helical channel in fluid communication with the fluid contact face;

wherein the sleeve and the fluid contact face define a compression chamber comprising an inlet and an outlet;

and wherein the sleeve and the plunger are rotatable relative to one another about a common longitudinal axis to adjust the overlap between the control hole and the helical channel for diverting flow of fluid from the compression chamber and out of the control hole during a discharge stroke to control flow of fluid pumped out of the outlet.

**18**. A reciprocating pump according to claim 17, wherein the sleeve is rotatable.

**19**. A reciprocating pump according to claim 18, wherein the control hole is in fluid communication with an overflow chamber.

**20**. A reciprocating pump according to claim 19, wherein the overflow chamber is in fluid communication with a fluid port upstream of the inlet.

**21**. A reciprocating pump according to claim 20, wherein the sleeve comprises a hollow cylinder with an opening for receiving the plunger.

**22**. A reciprocating pump according to claim 21, wherein the plunger comprises a cylinder.

**23**. A reciprocating pump comprising:

(a) a sleeve comprising a sidewall, the sidewall comprising a helical channel;

(b) a plunger receivable in the sleeve, the plunger comprising:

i. a fluid contact face;

ii. a sidewall;

iii. a bore in fluid communication with the fluid contact face, a first end of the bore defining a control hole formed in the sidewall;

wherein the sleeve and the fluid contact face define a compression chamber comprising an inlet and an outlet;

and wherein the sleeve and the plunger are rotatable relative to one another about a common longitudinal axis to adjust the overlap between the control hole and the channel for diverting flow of fluid from the compression chamber and out of the control hole during a discharge stroke to control flow of fluid pumped out of the outlet.

**24**. A reciprocating pump according to claim 23, wherein the sleeve is rotatable.

**25**. A reciprocating pump according to claim 24, wherein the helical channel is in fluid communication with an overflow chamber.

**26**. A reciprocating pump according to claim 25, wherein the overflow chamber is in fluid communication with a fluid port upstream of the inlet.

**27**. A reciprocating pump according to claim 26, wherein the sleeve comprises a hollow cylinder with an opening for receiving the plunger.

**28**. A reciprocating pump according to claim 27, wherein the plunger comprises a cylinder.

**29**. A reciprocating pump comprising:

(a) a sleeve;

(b) a plunger receivable in the sleeve, the plunger comprising a fluid contact face, wherein the sleeve and the fluid contact face define a compression chamber comprising an inlet and an outlet;

(c) an accumulator in fluid communication with the compression chamber for diverting flow of fluid away from the compression chamber during a discharge stroke to control flow of fluid pumped out of the output, the accumulator comprising:

i. a housing;

ii. a control element slidingly receivable in the housing, the control element comprising a fluid contact face, the fluid contact face and the housing defining an accumulation chamber;

iii. a moveable stop configured to adjustably define a maximum volume of fluid diverted to the accumulation chamber by restricting movement of the control element; and

iv. a force means biasing the control element away from the moveable stop.

**30**. A reciprocating pump according to claim 29 wherein the housing comprises a hydraulic cylinder.

**31**. A reciprocating pump according to claim 30 wherein the control element comprises a piston, and a travel of the piston is adjustably restricted by the moveable stop.

**32**. A reciprocating pump according to claim 31 wherein a first pressure exerted by the force means is less than a second pressure sufficient to pump fluid out of the outlet.

**33**. A reciprocating pump according to claim 32 wherein the force means comprises a spring.

**34**. A reciprocating pump according to claim 33 wherein the spring comprises a compression spring.

**35**. A reciprocating pump according to claim 32 wherein the force means comprises a source of fluid pressure.

**36**. A reciprocating pump according to claim 35 wherein the fluid pressure is air pressure.

**37**. A reciprocating pump according to claim 31 wherein the moveable stop comprises an annular ring disposed in the housing, wherein the travel of the piston is restricted by abutment of a bearing surface of the piston against the annular ring.

**38**. A method of controlling flow of fluid pumped by a reciprocating pump during a discharge stroke, the method comprising:

(a) providing a reciprocating pump comprising a sleeve and a plunger receivable in the sleeve, the sleeve comprising a first flow path element, the plunger comprising a face and a second flow path element in fluid communication with the face, wherein the sleeve and the face define a compression chamber comprising an inlet and an outlet, and the sleeve and the plunger are rotatable along a common axis relative to one another; and

(b) rotatably adjusting overlap between the first flow path element and the second flow path element to divert flow of fluid from the compression chamber and out of the control hole.

**39**. A method according to claim 38 wherein step (b) comprises rotating the sleeve.

**40**. A method according to claim 38 wherein step (b) comprises rotating the plunger.

**41**. A method according to claim 40 further comprising:

(c) allowing fluid flowing out of the second flow path element to flow to an overflow chamber.

**42**. A method according to aspect claim 41 further comprising:

(d) allowing fluid from the overflow chamber to flow to a fluid port upstream of the inlet.

**43**. A method of controlling flow of fluid pumped by a reciprocating pump during a discharge stroke, the method comprising:

(a) providing a reciprocating pump comprising a compression chamber and an accumulator in fluid communication with the compression chamber, the accumulator comprising:

i. a housing;

ii. a control element slidingly receivable in the housing, the control element comprising a fluid contact face, the fluid contact face and the housing defining an accumulation chamber; and

iii. a moveable stop configured to restrict movement of the control element to define a maximum volume of the accumulation chamber;

(b) moving the moveable stop to adjust the maximum volume of the accumulation chamber to control a volume of fluid diverted from the compression chamber to the accumulation chamber.

**44**. A method according to claim 43 wherein step (a) comprises providing a force means to bias the control element away from the moveable stop.

**45**. A method according to claim 44 wherein step (a) comprises maintaining a first pressure exerted by the force means to be less than a second pressure sufficient to pump fluid out of an outlet of the reciprocating pump.

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