(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
27 June 2013 (27.06.2013)

W I P O | P C T

(10) International Publication Number
WO 2013/092390 Al

(51) International Patent Classification:
F04B 7/00 (2006.01) *F04B 49/16* (2006.01)
F04B 35/01 (2006.01) *F04B 49/22* (2006.01)
F04B 39/10 (2006.01)

(21) International Application Number: PCT/EP2012/075438

(22) International Filing Date: 13 December 2012 (13. 12.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
CO 201 1 A 000071 22 December 201 1 (22. 12.201 1) IT

(71) Applicant: NUOVO PIGNONE S.P.A [IT/IT]; Via Felice Matteucci, 2, 1-50127 Florence (IT).

(72) Inventors: BAGAGLI, Riccardo; Via Felice Matteucci, 2, 1-50127 Firenze (IT). TOGNARELLI, Leonardo; Via Felice Matteucci, 2, 1-50127 Firenze (IT).

(74) Agent: ILLINGWORTH-LAW, William; GE International Inc, Global Patent Operation-Europe, 15 John Adem Streeet, London WC2N 6LU (GB).

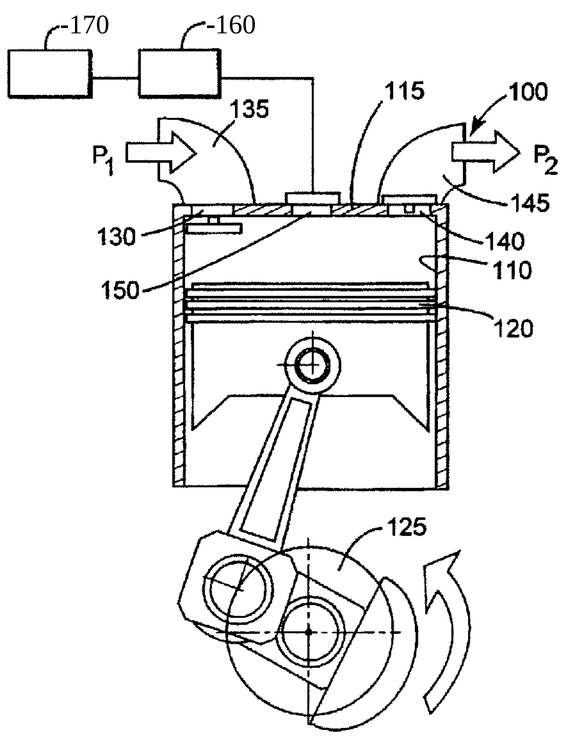
(81) Designated States *(unless otherwise indicated, for every kind of national protection available):* AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available):* ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,

[Continued on next page]

(54) Title: RECIPROCATING COMPRESSORS HAVING TIMING VALVES AND RELATED METHODS

Figure 3



(57) Abstract: Reciprocating compressors for the oil and gas industry with a timing valve and related methods are provided. A reciprocating compressor 100 has a chamber 110, a timing valve 150, an actuator 160 and a controller 170. A fluid entering the chamber 110 via a suction valve 130 is compressed inside the chamber, and evacuated from the chamber via a discharge valve 140. The timing valve is located between the chamber and a fluid volume at a relief pressure that is lower than a pressure in the chamber when the timing valve is opened. The actuator is configured to actuate the timing valve. The controller is configured to control the actuator such that to open the timing valve during an expansion phase of the compression cycle, and to close the timing valve when the relief pressure becomes equal to the pressure in the chamber or when the suction valve is opened.

WO 2013/092390 A1

TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

RECIPROCATING COMPRESSORS HAVING TIMING VALVES AND RELATED METHODS

BACKGROUND

TECHNICAL FIELD

Embodiments of the subject matter disclosed herein generally relate to reciprocating compressors used in oil and gas industry, and, more particularly, to increasing a suction volume and mitigating the effect of the clearance volume by using a timing valve that is actuated to open during the expansion phase of the compression cycle.

DISCUSSION OF THE BACKGROUND

Compressors used in oil and gas industry, have to meet industry specific requirements that take into consideration, for example, that the compressed fluid is frequently corrosive and combustible. American Petroleum Institute (API), the organization setting the recognized industry standard for equipment used in oil and gas industry has issued a document, API618, listing a complete set of minimum requirements for reciprocating compressors.

The compressors may be classified as positive displacement compressors (e.g., reciprocating, screw, or vane compressors) or dynamic compressors (e.g., centrifugal or axial compressors). In the positive displacement compressors, the compression is achieved by trapping the gas and then reducing volume in which the gas is trapped. In the dynamic compressors, the compression is achieved by transforming the kinetic energy (e.g., of a rotating element) into pressure energy at a predetermined location inside the compressor.

Figure 1 is an illustration of a conventional dual chamber reciprocating compressor 10 used in the oil and gas industry. Single chamber reciprocating compressors are less frequently used, but operate according to a similar compression cycle as the dual chamber reciprocating compressors.

In the reciprocating compressor 10, the fluid compression occurs in a cylinder 20. A fluid to be compressed (e.g., natural gas) is input into the cylinder 20 via an inlet 30 and through valves 32 and 34, and, after the compression, it is output via valves 42 and 44 and then an outlet 40. The compression is a cyclical process in which the fluid is compressed due to a movement of the piston 50 along the longitudinal axis of the cylinder 20, between a head end 26 and a crank end 28. In fact, the piston 50 divides the cylinder 20 in two chambers 22 and 24 operating in different phases of the compression cycle, the volume of chamber 22 being at its lowest value when the volume of the chamber 24 is at its highest value and vice-versa.

Suction valves 32 and 34 open at different times to allow the fluid that is going to be compressed from the inlet 30 into the chambers 22 and 24, respectively. Discharge valves 42 and 44 open to allow the fluid that has been compressed to be output from the chambers 22 and 24, respectively, via the outlet 40. The piston 50 moves due to energy transmitted from a crankshaft 60 via a crosshead 70 and a piston rod 80. Conventionally, the suction and the discharge valves (e.g., 32, 34, 42, and 44) used in a reciprocating compressor are automatic valves that are switched between a close state and an open state due to a differential pressure across the valve.

An ideal compression cycle (graphically illustrated in Figure 2 by tracking evolution of pressure versus volume) includes at least four phases: expansion, suction, compression and discharge. When the compressed fluid is evacuated from a chamber at the end of a compression cycle, a small amount of fluid at the delivery pressure P_i remains trapped in a clearance volume V_i (i.e., the minimum volume of the chamber). During the expansion phase 1 and the suction phase 2 of the compression cycle, the piston moves to increase the volume of the chamber. At the beginning of the expansion phase 1, the delivery valve closes (the suction valve remaining closed), and then, the pressure of the trapped fluid drops since the volume of the chamber available to the fluid increases. The suction phase of the compression cycle begins when the pressure inside the chamber becomes equal to the suction pressure P_2, triggering the suction valve to open at volume V_2. During the suction phase 2, the chamber volume and the amount of fluid to be compressed (at the pressure P_2) increase until a maxim volume of the chamber V_3 is reached.

During the compression and discharge phases of the compression cycle, the piston moves in a direction opposite to the direction of motion during the expansion and suction phases, to decrease the volume of the chamber. During the compression 3 phase both the suction and the delivery valves are closed (i.e. the fluid does not enter or exits the cylinder), the pressure of the fluid in the chamber increasing (from the suction pressure P_2 to the delivery pressure ***Pi)*** because the volume of the chamber decreases to *v4.* The delivery phase 4 of the compression cycle begins when the pressure inside the chamber becomes equal to the delivery pressure *Pi,* triggering the delivery valve to open. During the delivery phase 4 the fluid at the delivery pressure *Pi* is evacuated from the chamber until the minimum (clearance) volume *Vi* of the chamber is reached.

One measure of the efficiency of the compressor is the volumetric efficiency which is a ratio between the volume $v3\text{-}V_2$ of the chamber swept by the piston of the reciprocating compressor during the suction phase and the total volume *v3- Vi* swept by the piston during the compression cycle. One can consider that the purpose of a compressor is to deliver as much compressed fluid as possible. The larger the volumetric efficiency the more fluid is compressed in each compression cycle. One important source of inefficiency in the reciprocating compressor is due to the clearance volume, which is a volume of compressed gas which is not delivered from the chamber during to the delivery phase.

If a suction valve would open early, before the pressure inside the chamber drops due to the gas expansion, to the suction pressure *Pi,* then some of the compressed air remaining in the chamber would exit the chamber. However, the force necessary to open the suction valve is large, proportional with the area of the valve and a pressure difference across the suction valve (i.e., the pressure difference between the pressure inside the chamber and the suction pressure). Such a large force would require a large actuator which would also have a short actuation time. At a practical level, opening the suction valve early is not currently feasible.

Accordingly, it would be desirable to provide methods and devices useable in reciprocating compressors for the oil and gas industry that have an effect similar to early opening of the suction valve.

SUMMARY

Some of the embodiments relate to a timing valve opened during an expansion phase of a chamber in a reciprocating compressor used in oil and gas industry. The presence and operation of the timing valve results in an increased suction volume (and, therefore, volumetric efficiency) and mitigates the effect of the clearance volume.

According to one exemplary embodiment, a reciprocating compressor has a chamber, a timing valve, an actuator and a controller. A fluid entering the chamber via a suction valve is compressed inside the chamber, and the compressed fluid is evacuated from the chamber via a discharge valve. The timing valve is located between the chamber and a fluid volume at a relief pressure that is lower than a pressure in the chamber when the timing valve is opened. The actuator is configured to actuate the timing valve. The controller is configured to control the actuator such that to open the timing valve during an expansion phase of the compression cycle, and to close the timing valve when the relief pressure becomes equal to the pressure in the chamber or when the suction valve is opened.

According to another exemplary embodiment, a method of improving a volumetric efficiency of a reciprocating compressor is provided. The method includes providing a timing valve located between a chamber of the reciprocating compressor and a volume of fluid at a relief pressure, and controlling the timing valve to opened during an expansion phase of a compression cycle, while the relief pressure is smaller than a pressure inside the chamber. The timing valve has a flow area smaller than a flow area of a suction valve of the reciprocating compressor.

According to another exemplary embodiment, a method of retrofitting a compressor to evacuate fluid from a chamber during an expansion phase of a compression cycle is provided. The method includes (1) providing a timing valve located between the chamber and a volume of fluid at a relief pressure, (2) mounting an actuator configured to actuate the timing valve, and (3) connecting a controller to the actuator. The controller is configured to control the actuator such the timing valve to be opened during the expansion phase of the compression cycle, while a pressure in the chamber is larger than the relief pressure.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate one or more embodiments and, together with the description, explain these embodiments. In the drawings:

Figure 1 is a schematic diagram of a conventional dual chamber reciprocating compressor;

Figures 2 is a pressure versus volume graphic illustrating an ideal compression cycle;

Figure 3 is schematic diagram of a reciprocating compressor, according to an exemplary embodiment;

Figure 4 is a pressure versus volume graphic illustrating the effect of the timing valve, according to an exemplary embodiment;

Figure 5 illustrates an arrangement of valves on a head end of a reciprocating compressor, according to an exemplary embodiment;

Figure 6 illustrates an arrangement of valves on a head end of a dual chamber reciprocating compressor, according to an exemplary embodiment;

Figure 7 illustrates an arrangement of valves on a crank end of a dual chamber reciprocating compressor, according to an exemplary embodiment;

Figure 8 is a flow chart of a method of improving a volumetric efficiency of a reciprocating compressor, according to an exemplary embodiment; and

Figure 9 is a flow diagram of a method of retrofitting a reciprocating compressor to evacuate fluid from a chamber during an expansion phase of a compression cycle, according to another exemplary embodiment.

DETAILED DESCRIPTION

The following description of the exemplary embodiments refers to the accompanying drawings. The same reference numbers in different drawings identify the same or similar elements. The following detailed description does not limit the invention. Instead, the scope of the invention is defined by the appended claims. The following embodiments are discussed, for simplicity, with regard to the terminology and structure of reciprocating compressors used in oil and gas industry. However, the embodiments to be discussed next are not limited to this equipment, but may be applied to other equipment.

Reference throughout the specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with an embodiment is included in at least one embodiment of the subject matter disclosed. Thus, the appearance of the phrases "in one embodiment" or "in an embodiment" in various places throughout the specification is not necessarily referring to the same embodiment. Further, the particular features, structures or characteristics may be combined in any suitable manner in one or more embodiments.

In some embodiments described below, the volumetric efficiency of a reciprocating compressor is improved by using a timing valve opened during an expansion phase of a compressing cycle, to allow a fluid to exit the chamber of the reciprocating compressor. The timing valve is connected to a fluid volume having a relief pressure that is lower than the pressure of the fluid in the chamber.

Figure 3, illustrates a reciprocating compressor 100, according to an exemplary embodiment. The reciprocating compressor 100 has a single chamber 110. However, the current inventive concept is also applicable to dual chamber reciprocating compressors.

A piston 120 performs a reciprocating motion to compress a fluid inside the chamber 110. The piston 120 receives the reciprocating motion from a crank shaft 125. The piston 120 moves towards and away from a head end 115 of the chamber 110. In other words, the head end 115 is perpendicular to a direction along which the piston 120 moves.

The fluid to be compressed enters the chamber 110 via a suction valve 130, from a suction duct 135. After being compressed, the fluid is evacuated from the chamber 110 via a discharge valve 140 towards a discharge duct 145. In the illustrated embodiment, the suction valve 130 and the discharge valve 145 are located on the head end 115 of the chamber 110.

A timing valve 150 is configured to allow the fluid to exit the chamber during an expansion phase of a compression cycle in the chamber 110. The timing valve 150 is actuated by an actuator 160. The timing valve 150 is located between the chamber 110 and a volume of fluid having a relief pressure that is smaller than the pressure in the chamber 110. In Figure 3, the timing valve 150 is connected to the suction valve 135, but in other embodiments, the timing valves may be connected differently to a separate volume of fluid having a relief pressure that is lower than a pressure in the chamber 110 while the timing valve 150 is opened.

The timing valve 150 is an actuated valve. The force necessary to open the timing valve is proportional with the difference of pressure between opposite sides of the timing valve 150 and the flow area of the timing valve 150. In order to generate a large force, a big (volume-wise) actuator would be necessary. Therefore, the flow area of the timing valve 150 is smaller (even substantially smaller) than the flow area of the suction valve 130, such as to be possible to open the timing valve 150 using a small (volume-wise) actuator 160.

The controller 170 controls the actuator 160 to open the timing valve 170 during the expansion phase of the compression cycle. The smaller the force that the actuator 160 has to provide to open the valve 150 the earlier the timing valve 150 can be opened. The controller 170 controls the actuator 160 to close the timing valve 150 after the pressure in the chamber 110 becomes equal to the relief pressure or after the suction valve 130 opens. The timing valve 150 has to be closed before the end of the suction phase of the compression cycle. Since in the embodiment illustrated in Figure 3, the timing valve 150 is connected to the suction duct 135, the relief pressure is the suction pressure P_2.

The suction valve 130 may be an automatic valve opening when pressure in the chamber is substantially equal to a pressure of the fluid in a suction duct, the suction valve being located between the chamber and the suction duct. However, the suction valve may be also an actuated valve and its actuator (not shown) may be controlled by the controller 170.

The pressure versus volume graph in Figure 4 illustrates the effect of using the timing valve 150. If the timing valve were not used, as illustrated in Figure 2, the expansion phase 1 is a polytropic process pV^n=constant (where ideally **n=Y** for adiabatic process), ending when the pressure in the chamber equals the suction pressure P_2 triggering the suction valve 130 to open. The timing valve 150 is opened when pressure in the chamber is P_A (point A on the graph) due to a force generated by the actuator 160. If the flow area of the timing valve 150 was large or the piston 120 was not continuing to move after the timing valve is opened (i.e., the volume of the chamber 110 would remain constant), an isochoric process A-A' would have taken place in the chamber 110. (i.e., the pressure would drop for a constant volume V_A illustrated as a vertical line in the graph).

However, in reality, the flow area of the timing valve 150 is small and the piston 120 continues to move after the timing valve is opened. The pressure inside the chamber 110 drops due to the motion of the piston 120 increasing the volume of the chamber 110 and because fluid exits the chamber 110 through the timing valve 150. The line A-A" in the graph represents the pressure dependence of volume after the opening of the timing valve 150. The line A-A" is located between curve A-(P_2,V_2) corresponding to the expansion without opening the timing valve, and the vertical line A-A' corresponding to an isochoric process. This expansion that takes place while the timing valve 150 is opened leads faster (compared to when the timing valve is not opened) to a pressure inside the chamber 110 equal to the suction pressure Pi.

Additionally, the volume V'_A at the end of the expansion while using the timing valve is smaller than the volume V_2 at the end of the expansion phase without using the timing valve. Since $V'_A < V_2$, the volumetric efficiency (which is a ratio between the volume of the chamber swept by the piston of the reciprocating compressor during the suction phase and the total volume swept by the piston during the compression cycle) increases.

In some embodiments, plural timing valves are used in a reciprocating compressor. For example, Figure 5 illustrates an arrangement of timing valves on the head end 215 of a single or a dual reciprocating compressor. In this arrangement, two timing valves 250 and 255 are arranged substantially symmetrical relative to a middle O of the head end 215. The suction valve 230 and the discharge valve 240 are also arranged substantially symmetrical relative to the middle O of the head end 215.

The reciprocating compressor 100 illustrated in Figure 3 is a reciprocating compressor having a single chamber. However, the same inventive concept may be applied to a dual chamber reciprocating compressor having a cylinder divided in two chambers by a piston. A timing valve may be provided for one or both chambers of a dual chamber reciprocating compressor. Two suction valves 330 and 332, two discharge valves 340 and 342 and a timing valve 350 may all be arranged on a head end 315 of a dual chamber reciprocating compressor as illustrated in Figure 6.

The valves may be arranged on a head end and/or on a crank end of a dual chamber reciprocating compressor. Two suction valves, 430 and 432, two discharge valves, 440 and 442, and two timing valves, 450 and 452, may be arranged on a crank end 416 of a dual chamber reciprocating compressor as illustrated in Figure 7. The head end and the crank end of the dual chamber reciprocating compressor are substantially perpendicular on a direction along which the piston moves. The crank end 416 has an additional opening 418 through which the piston receives the reciprocating motion (e.g., from a crankshaft via a rod and a crosshead).

However, in yet another embodiment, (1) the suction valve, the discharge valve, and the timing valve of one chamber may be located on a head end of the cylinder of a dual reciprocating compressor, and (2) the suction valve, the discharge valve, and the timing valve of the other chamber may be located on the crank end of the cylinder.

A flow diagram of a method 500 of improving a volumetric efficiency of a reciprocating compressor is illustrated in Figure 8. The method 500 includes providing a timing valve located between a chamber of the reciprocating compressor and a volume of fluid at a relief pressure, at S510. Further, the method 500 includes controlling the timing valve to be opened during an expansion phase of a compression cycle performed inside the chamber, while the relief pressure is smaller than a pressure inside the chamber, at S520. The timing valve has a flow area smaller than a flow area of a suction valve of the reciprocating compressor.

Existing reciprocating compressors may be retrofitted to improve their volumetric efficiency. A flow diagram of a method 600 of retrofitting a reciprocating compressor to evacuate fluid from a chamber during an expansion phase of a compression cycle is illustrated in Figure 9. The method 600 includes providing a timing valve on the chamber, the timing valve being located between the chamber and a volume of fluid at a relief pressure, at S610. The method 600 further includes mounting an actuator configured to actuate the timing valve, at S620, and connecting a controller to the actuator, at S630. The controller is configured to control the actuator such that the timing valve to be opened during the expansion phase of the compression cycle, while a pressure in the chamber is larger than the relief pressure. The timing valve may be is connected to the suction duct to which the suction valve of the reciprocating compressor is also connected. The flow area of the timing valve may be substantially smaller than the area of a suction valve of the chamber.

The disclosed exemplary embodiments provide methods and devices used in reciprocating compressors to increase a suction volume (and, thus, the volumetric efficiency) and to mitigate the effect of the clearance volume by using a timing valve that is actuated to open during the expansion phase of the compression cycle. It should be understood that this description is not intended to limit the invention. On the contrary, the exemplary embodiments are intended to cover alternatives, modifications and equivalents, which are included in the spirit and scope of the invention as defined by the appended claims. Further, in the detailed description of the exemplary embodiments, numerous specific details are set forth in order to provide a comprehensive understanding of the claimed invention. However, one skilled in the art would understand that various embodiments may be practiced without such specific details.

Although the features and elements of the present exemplary embodiments are described in the embodiments in particular combinations, each feature or element can be used alone without the other features and elements of the embodiments or in various combinations with or without other features and elements disclosed herein.

This written description uses examples of the subject matter disclosed to enable any person skilled in the art to practice the same, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the subject matter is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims.

CLAIMS:

1. A reciprocating compressor, comprising:

a chamber inside which a fluid entering the chamber via a suction valve is compressed, and the compressed fluid is evacuated from the chamber via a discharge valve;

a timing valve located between the chamber and a fluid volume at a relief pressure that is lower than a pressure in the chamber when the timing valve is opened;

an actuator configured to actuate the timing valve; and

a controller configured to control the actuator such that to open the timing valve during an expansion phase of the compression cycle, and to close the timing valve when the relief pressure becomes equal to the pressure inside the chamber or when the suction valve is opened.

2. The reciprocating compressor of claim 1, wherein the timing valve has a flow area smaller than a flow area of the suction valve.

3. The reciprocating compressor of claim 1 or claim 2, wherein the timing valve is located on a head end of the chamber, the head end being substantially perpendicular on a direction along which the piston moves.

4. The reciprocating compressor of any preceding claim, further comprising:

another timing valve configured to allow the fluid to exit the chamber during the expansion phase of the compression cycle, the timing valve and the other timing valve having areas substantially smaller than an area of the suction valve; and

another actuator configured to open the other timing valve, wherein the controller is further configured to control the other actuator (1) to open the other timing valve during an expansion phase of the compression cycle in the other chamber thereby allowing fluid to exit thereof, and (2) to close the other timing when the relief pressure becomes equal to the pressure in the other chamber or when the other suction valve is opened.

5. The reciprocating compressor of any preceding claim, wherein at least one of following conditions is met:

the timing valve and the other timing valve have substantially equal areas.

the controller is configured to control the actuator and the other actuator to open the timing valve and the other timing valve at substantially the same moment, and

the suction valve, the discharge valve, the timing valve and the other timing valve are located on a head end of the chamber, the head end being substantially perpendicular on a direction along which the piston moves.

6. The reciprocating compressor of any preceding claim, wherein the timing valve and the suction valve are connected between the chamber and a suction duct through which the fluid to be compressed is supplied to the chamber.

7. The reciprocating compressor of any preceding claim, wherein

the reciprocating compressor is a dual reciprocating compressor having a cylinder divided in two chambers by the piston, the chamber and another chamber configured to increase pressure of fluid entering the other chamber via another suction valve and being evacuated from the other chamber via another discharge valve, and

the suction valve, the other suction valve, the discharge valve, the other discharge valve and the timing valve are located on a head end of the cylinder, the head end being substantially perpendicular on a direction along which the piston moves.

8. The reciprocating compressor of any preceding claim, wherein

the reciprocating compressor is a dual reciprocating compressor having a cylinder divided in two chambers by the piston, the chamber and another chamber configured to increase pressure of fluid entering the other chamber via another suction valve and being evacuated from the other chamber via another discharge valve, and

the reciprocating compressor further comprises another timing valve configured to allow the fluid to exit the other chamber during an expansion phase of a compression cycle in the other chamber, and

(A) the suction valve, the other suction valve, the discharge valve, the other discharge valve, the timing valve and the other timing valve are located on a head end or on a crank end of the cylinder, or

(B) the suction valve, the discharge valve, and the timing valve are located on a head end of the cylinder, and the other suction valve, the other discharge valve, and other the timing valve are located on a crank end of the cylinder.

9. A method of improving a volumetric efficiency of a reciprocating compressor, comprising:

providing a timing valve located between a chamber of the reciprocating compressor and a volume of fluid at a relief pressure;

controlling the timing valve to be opened during an expansion phase of a compression cycle performed inside the chamber while the relief pressure is smaller than a pressure inside the chamber, wherein the timing valve has a flow area smaller than a flow area of a suction valve of the reciprocating compressor.

10. A method of retrofitting a compressor to evacuate a fluid from a chamber during an expansion phase of a compression cycle, the method comprising:

providing a timing valve located between the chamber and a volume of fluid at a relief pressure;

mounting an actuator configured to actuate the timing valve; and

connecting a controller to the actuator, the controller being configured to control the actuator such that the timing valve to be opened during the expansion phase of the compression cycle, while a pressure in the chamber is larger than the relief pressure.

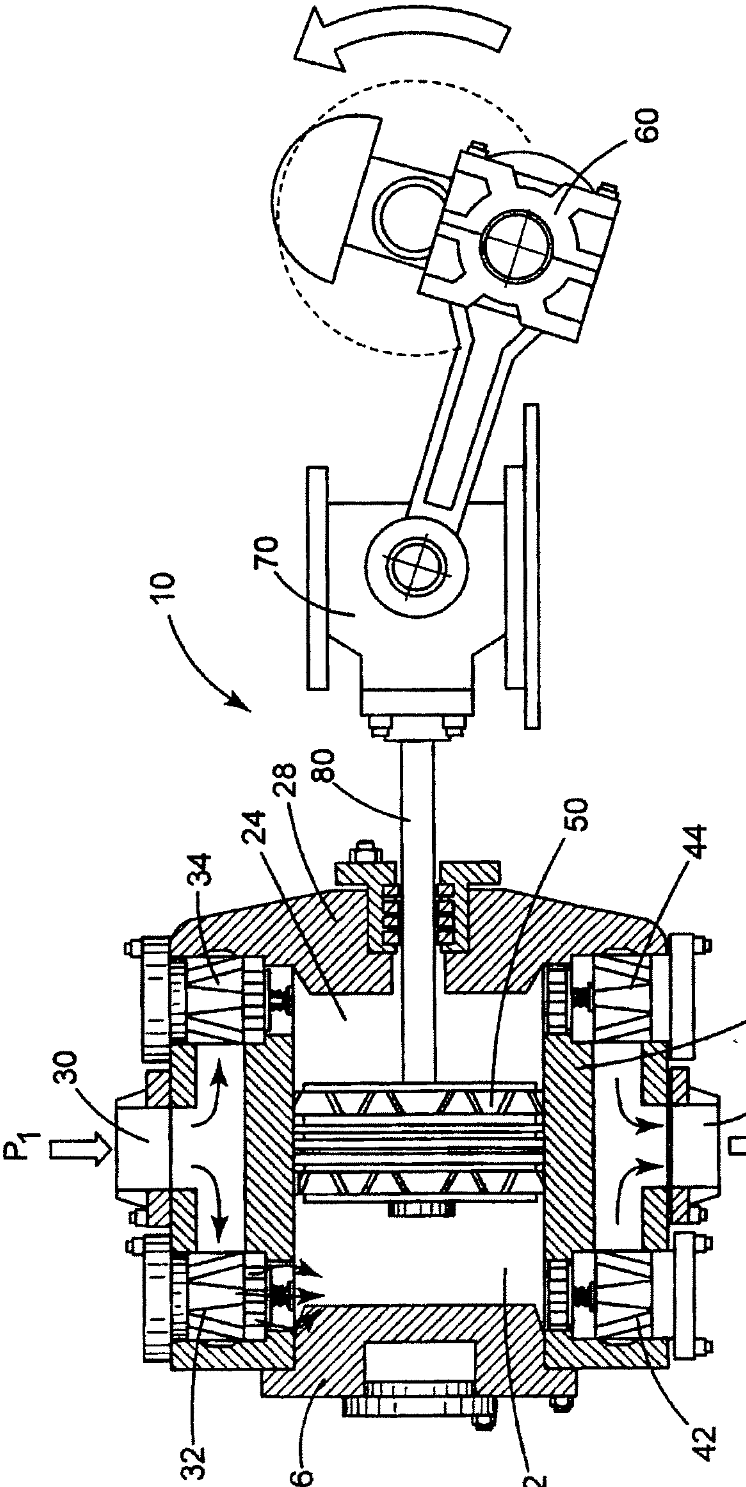


Figure 1
Background Art

Figure 2

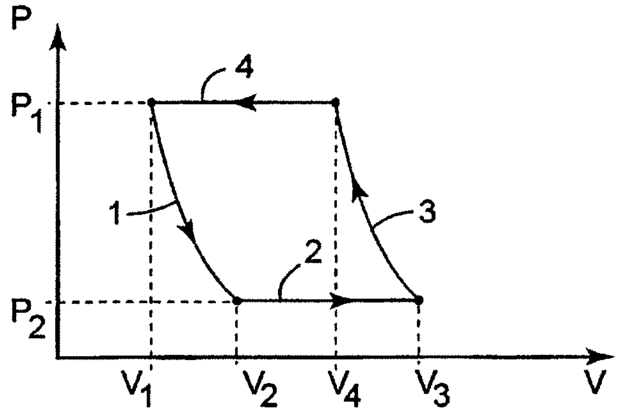


Figure 3

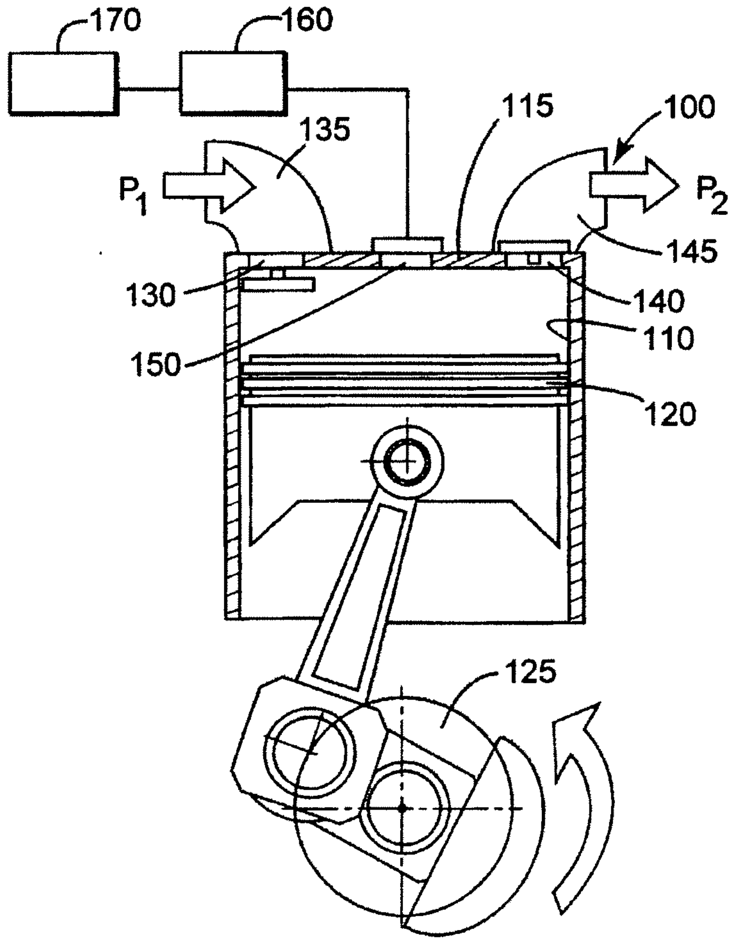


Figure 4

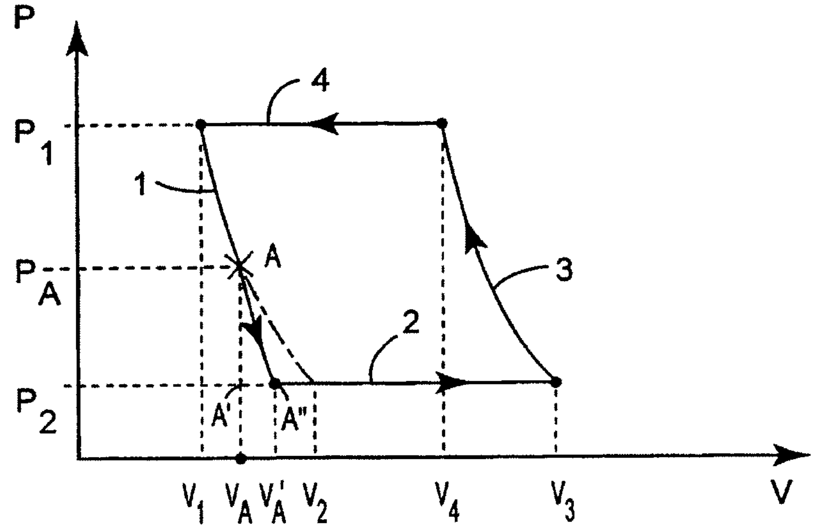


Figure 5

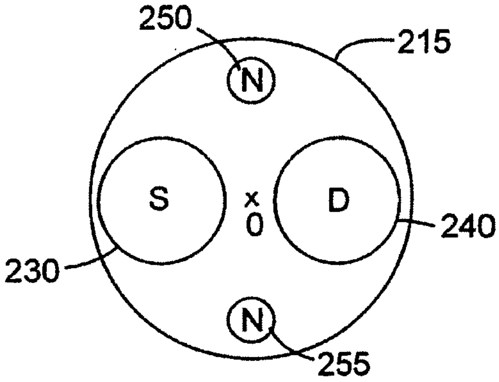


Figure 6

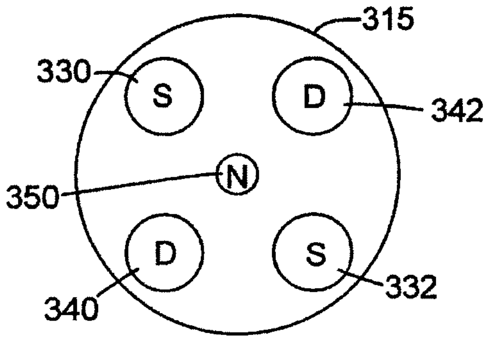


Figure 7

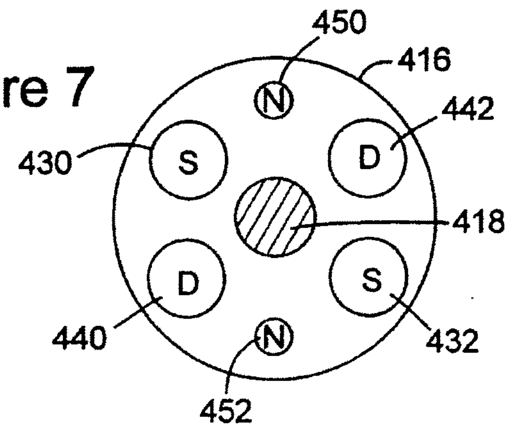


Figure 8

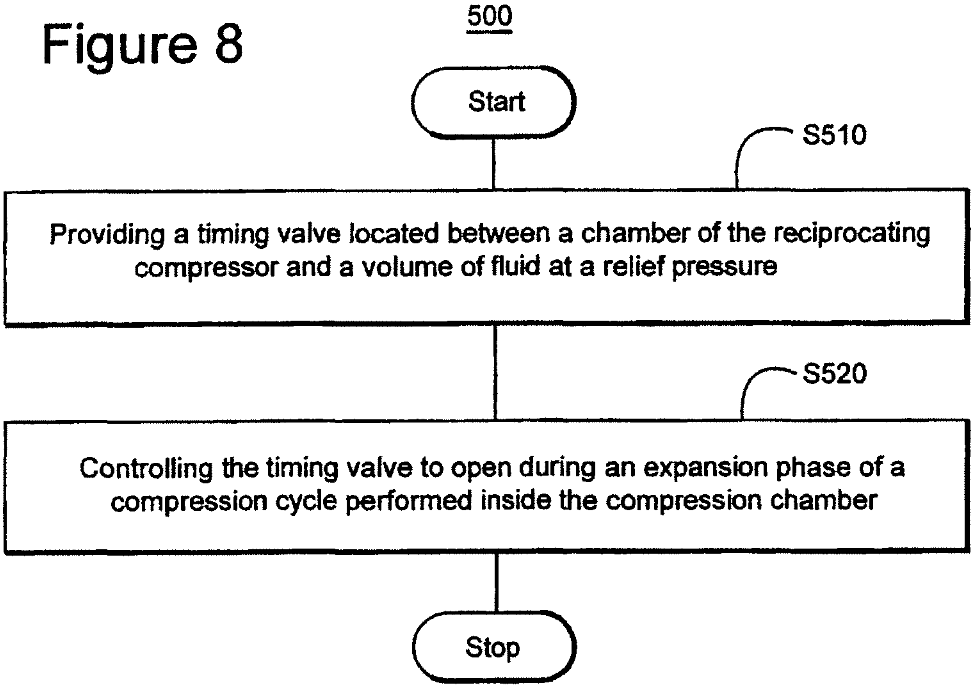
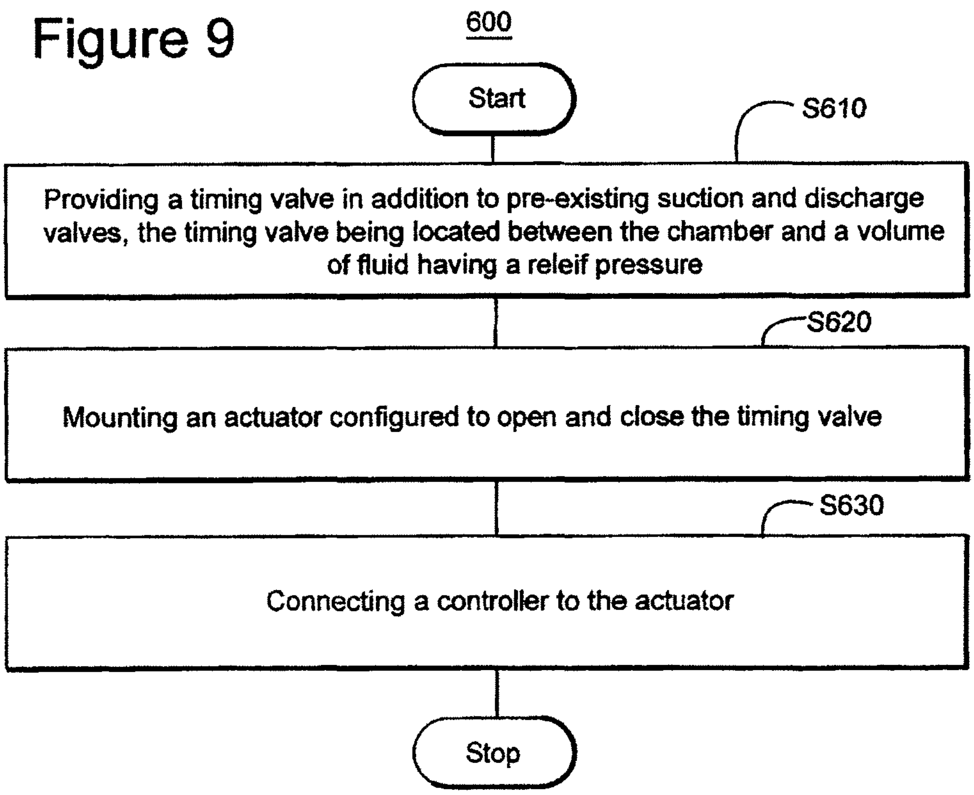


Figure 9



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/075438

A. CLASSIFICATION OF SUBJECT MATTER
INV. F04B7/00 F04B35/01 F04B39/10 F04B49/16 F04B49/22
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 201 953 605 U (BEIBIAO JIN) 31 August 2011 (2011-08-31)	1-3,6,9
Y	the whole document	4,5,7,8, 10

Y	FR 1 030 602 A (DUJARDIN & CIE SA DES ETS) 16 June 1953 (1953-06-16) page 4, paragraph 1; figures 6,7	4,5

Y	US 4 480 965 A (ISHIZUKA YUTAKA [JP]) 6 November 1984 (1984-11-06) column 2, line 35 - column 5, line 12; figures 1-3	7,8, 10

A	US 2010/269799 A1 (MELLAR J0ERG [DE]) 28 October 2010 (2010-10-28) paragraphs [0030] - [0033]; figure 2	1-10

	-/-	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 May 2013	22/05/2013

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Jurado Orenes, A

1

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/075438

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3 972 652 A (MINNICINO MICHAEL ANTHONY) 3 August 1976 (1976-08-03) column 2, line 13 - column 4, line 22; figures 1-3 -----	1-10

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2012/075438

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
CN 201953605	U	31-08-2011	CN 102141025	A	03-08-2011
			CN 201953605	U	31-08-2011
			WO 2012079269	A1	21-06-2012
FR 1030602	A	16-06-1953	NONE		
US 4480965	A	06-11-1984	JP S5862387	A	13-04-1983
			US 4480965	A	06-11-1984
US 2010269799	A1	28-10-2010	CN 101835985	A	15-09-2010
			DE 102007051940	A1	30-04-2009
			EP 2205870	A1	14-07-2010
			JP 2011501044	A	06-01-2011
			KR 20100070354	A	25-06-2010
			RU 2010121885	A	10-12-2011
			US 2010269799	A1	28-10-2010
			WO 2009056245	A1	07-05-2009
US 3972652	A	03-08-1976	CA 1048462	A1	13-02-1979
			FR 2311198	A1	10-12-1976
			JP S51140210	A	03-12-1976
			US 3972652	A	03-08-1976