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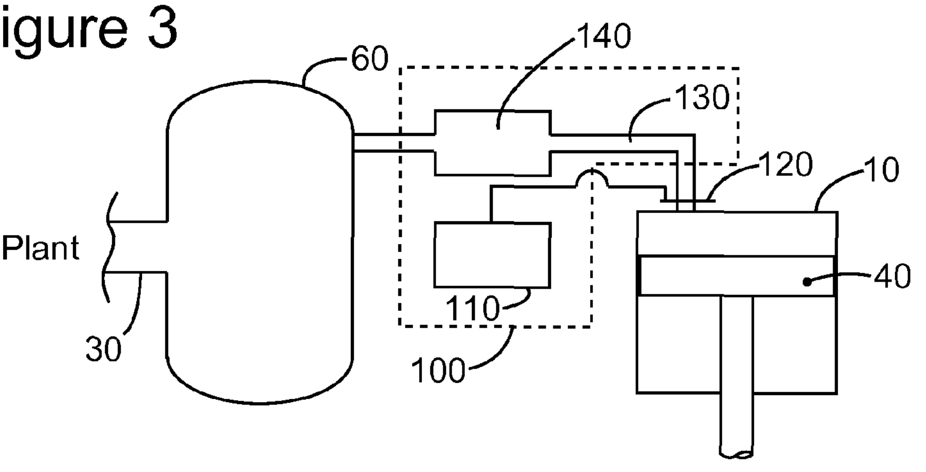
(54) **Methods and devices for constructively using the pressure pulsations in reciprocating compressors installations**

(57) Apparatuses and methods for constructively use pressure pulses to enhance the volumetric efficiency of a reciprocating compressor are provided. An apparatus includes a gas circulation device and a controller 110. The gas circulation device provides a path through which the gas circulates between a reciprocating compressor 10 and a volume bottle 50 buffering the reciprocating compressor from an installation. The gas circulation device is configured to have to have a resonance frequency substantially equal to a frequency of performing compression cycles in the reciprocating compressor. The controller 110 is configured to control timing of switching a valve located between the reciprocating compressor and the gas circulation device, in order to use constructively pressure pulsations occurring in the gas circulation device, to enhance the volumetric efficiency of the reciprocating compressor.

Figure 3



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Description

BACKGROUND

TECHNICAL FIELD

[0001] Embodiments of the subject matter disclosed herein generally relate to installations using reciprocating compressors in oil and gas industry, and, more particularly, to constructively using the pressure pulsations to enhance the volumetric efficiency of the compressor, i.e., achieving a pulse charging effect.

DISCUSSION OF THE BACKGROUND

[0002] Compressors used in oil and gas industry have to meet industry specific requirements that take into consideration, for example, that the compressed gas is frequently corrosive and flammable. 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.

[0003] The compressors may be classified in positive displacement compressors (e.g., reciprocating, screw, or vane compressors) and 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.

[0004] An ideal compression cycle (graphically illustrated in Figure 1 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 compression chamber at the end of a compression cycle, a small amount of fluid at the delivery pressure P_1 remains trapped in a clearance volume V_1 (i.e., the minimum volume of the compression chamber). During the expansion phase 1 and the suction phase 2 of the compression cycle, the piston moves to increase the volume of the compression 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 compression chamber available to the fluid increases. The suction phase of the compression cycle begins when the pressure inside the compression 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 compression chamber volume and the amount of fluid to be compressed (at the pressure P_2) increase until a maximum volume of the compression chamber V_3 is reached.

[0005] 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 compression chamber. During the compression phase 3 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 compression chamber increasing (from the suction pressure P_2 to the delivery pressure P_1) because the volume of the compression chamber decreases to V_4. The delivery phase 4 of the compression cycle begins when the pressure inside the compression chamber becomes equal to the delivery pressure P_1, triggering the delivery valve to open. During the delivery phase 4 the fluid at the delivery pressure P_2 is evacuated from the compression chamber until the minimum (clearance) volume V_1 of the compression chamber is reached.

[0006] One measure of the efficiency of the compressor is the volumetric efficiency, which is a ratio of the volume of the compression chamber swept by the piston of the reciprocating compressor during the suction phase V_3- V_2 to the total volume V_3- V_1 swept by the piston during the compression cycle.

[0007] The phenomenon of pressure pulsations occurring outside the reciprocating compressor is due to the discontinued nature of the gas flow inside the reciprocating compressor. These pressure pulsations may lead to large vibrations and fatigue stresses, high noise level, and reduced compressor performance. API618 includes the detailed requirements for an acoustical study that has to be undertaken when designing an installation including a reciprocating compressor, for, among other purposes, avoiding the damaging effect of the pressure pulsations. In order to prevent these pulsations from propagating throughout the installation, volume bottles are installed before the suction valves and after the discharge valves of the compressors, buffering the reciprocating compressor from the rest of the installation.

[0008] For example, Figure 2 illustrates a simplified model of an interface between a reciprocating compressor 10 and the rest of the installation. Here the term "interface" designates all the components between a valve 20 of the reciprocating compressor 10 and a plant pipe 30 through which gas is channeled to or from a rest of the installation (e.g., an oil and gas plant). The reciprocating compressor 10 has a piston 40, and is connected via a pipe 50 to a volume bottle 60. The volume bottle 60 is then connected to the oil and gas plant via the plant pipe 30.

[0009] The volume bottle 60 filled with the gas to be compressed or the compressed gas (depending on whether the volume bottle is located before the suction valve or after the discharge valve or the reciprocating compressor 10 has a high acoustical impedance and operates as a reflector of the pulsations, allowing only a small fraction to be transmitted towards the plant pipe 30.

[0010] The frequency of the pressure pulsations generated by the reciprocating compressor 10 is the frequency of the compression process in the reciprocating compressor. Resonance occurs when a natural frequency *f* of the pipe 30 equals the frequency of the pressure pulsations generated by the reciprocating compressor. The natural frequency *f* of the pipe 50 depends on the speed of sound in the gas c and the length *L* of the pipe 50. In a first approximation, the following relationship exists between these quantities: $f=c/(2L)$. If stationary pressure waves are formed along the pipe 50, orifices (i.e., localized narrowing of the pipe) may be employed to reduce the amplitude of the stationary pressure waves.

[0011] Thus, conventionally, the pressure pulsations (that inherently occur due to discontinued nature of the gas flow in a reciprocating compressor) are dissipated, not used.

[0012] It would be desirable to provide methods and devices (included or performed in oil and gas installations including a reciprocating compressor) that use constructively the pressure pulsation to enhance the efficiency of the reciprocating compressor.

SUMMARY

[0013] Some of the embodiments have an actuated valve and a gas circulation device configured to have a resonance frequency substantially equal to a frequency of performing compression cycles in the reciprocating compressor. The valve is actuated such as to enhance the volumetric efficiency of the compressor using constructively the inherent pressure pulsations. This manner of using the pressure pulses to enhance efficiency is known as the pulse charging effect.

[0014] According to one exemplary embodiment, an apparatus includes a gas circulation device and a controller. The gas circulation device provides a path through which gas (to be compressed or after being compressed) circulates between a reciprocating compressor and a volume bottle buffering a gas flow connecting of the reciprocating compressor to an oil and gas plant. The gas circulation device is configured to have a resonance frequency substantially equal to a frequency of performing compression cycles in the reciprocating compressor. The controller is configured to control timing of switching a valve located between the reciprocating compressor and the gas circulation device in order to use constructively pressure pulsations occurring in the gas circulation device to enhance a volumetric efficiency of the reciprocating compressor.

[0015] According to another exemplary embodiment, a method of using a pulse charging effect to enhance a volumetric efficiency of a reciprocating compressor is provided. The method includes providing a gas circulation device between a valve of the reciprocating compressor and a volume bottle buffering the reciprocating compressor from an oil and gas plant, the gas circulation device being configured to have a resonance frequency substantially equal to a frequency of performing compression cycles in the reciprocating compressor. The method further includes controlling timing of actuating the valve to use constructively pressure pulses inherently occurring in the gas circulation device, to enhance the volumetric efficiency of the reciprocating compressor.

[0016] According to another exemplary embodiment, a method for retrofitting a reciprocating compressor installation is provided. A reciprocating compressor of the installation has an output or an input thereof buffered by a volume bottle from the rest of the installation. The reciprocating compressor installation is retrofitted to use a pulse charging effect of the reciprocating compressor to enhance a volumetric efficiency thereof. The method includes modifying a gas circulation device connecting an output or an input of the reciprocating compressor to the volume bottle, by adding at least one acoustic resonator to a pipe of the gas circulation device, to make the gas circulation device to have a resonance frequency substantially equal to a frequency of performing compression cycles in the reciprocating compressor. The method further includes connecting a valve between the reciprocating compressor and the gas circulation device, to a controller configured to control timing of actuating the valve in order to use constructively pressure pulsations occurring in the gas circulation device, to enhance a volumetric efficiency of the reciprocating compressor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] 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 pressure versus volume graph illustrating an ideal compression cycle;

Figure 2 is a schematic diagram of a conventional interface between a reciprocating compressor and an oil and gas plant;

Figure 3 is a schematic diagram of an interface between a reciprocating compressor and an oil and gas plant, according to an exemplary embodiment;

Figure 4 is a schematic diagram of an interface between a reciprocating compressor and an oil and gas plant, according to an exemplary embodiment;

Figure 5 is a schematic diagram of an interface between a reciprocating compressor and an oil and gas plant, according to an exemplary embodiment;

Figure 6 is a schematic diagram of an interface between a reciprocating compressor and an oil and gas plant, according to an exemplary embodiment;

Figure 7 is a schematic diagram of an interface between a reciprocating compressor and an oil and gas plant, according to an exemplary embodiment;

Figure 8 is a schematic diagram of an interface between a reciprocating compressor and an oil and gas plant, according to an exemplary embodiment;

Figure 9 is flow chart of a method of using pulsations inherently generated during operation of a reciprocating compressor in order to enhance compressor's efficiency, according to an exemplary embodiment; and

Figure 10 is a flow chart of a method for retrofitting a reciprocating compressor installation, according to an exemplary embodiment.

DETAILED DESCRIPTION

[0018] 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 an oil and gas plant (i.e., installation or equipment). However, the embodiments to be discussed next are not limited to this system, but may be applied to other similar technical conditions.

[0019] 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.

[0020] In some embodiments described below, a gas circulation device, which provides a path through which gas (to be compressed or after being compressed) circulates between a reciprocating compressor (i.e., the compression chamber thereof) and a volume bottle. The gas circulation device is configured to have a resonance frequency substantially equal to a frequency of performing compression cycles in the reciprocating compressor. Furthermore, a valve located between the compression chamber and the gas circulating device is controlled to open relative to a phase of the pressure pulsations near the valve in the gas circulation device such that to enhance efficiency of the compressor.

[0021] If one considers that the valve is the suction valve, an increased pressure in the gas circulation device near the suction valve while the valve is open results in a larger amount of gas entering the volume of the compression chamber to be compressed. The suction taking place at a higher pressure $P_2+\Delta p$, where Δp is due to the pulse charging effect, is illustrated as a dashed line in Figure 1. Since the volume V_2' corresponding to the intersection of the dashed line with line representing the expansion phase 1 is smaller than V_2, the volumetric efficiency increases because the numerator of the ratio defining the volumetric efficiency increases $V_3 - V_2' > V_3 - V_2$.

[0022] In fact, Δp is not a constant offset of the pressure as it varies in time, between a maximum positive value and a maximum negative value. A controller may determine the opening moment of the valve 20 to have a maximum pressure Δp (added or subtracted) at the time of opening of the valve or achieve an overall pressure higher pressure than the suction pressure during (or at the end of) the suction phase.

[0023] Figure 3 is a schematic diagram of an interface 100 (i.e., an apparatus) between a reciprocating compressor 10 and a volume bottle 60 providing a gas volume buffer to an oil and gas plant according to an exemplary embodiment. The large volume of gas in the volume bottle 60 prevents or substantially damps pressure pulses occurring in gas outside the reciprocating compressor 10 due to flux variation in the reciprocating compressor 10 (i.e., due to the pulse charging effect). The interface 100 includes a gas circulation device and a controller 110. The gas circulation device provides a path through which the gas (to be compressed or after being compressed) circulates between the reciprocating compressor 10 and the volume bottle 50. The gas circulation device is configured to have a resonance frequency substantially equal to a frequency of performing compression cycles in the reciprocating compressor. The gas circulation device includes a pipe 130 and an in-line resonator 140 having an area larger than the pipe area. The exact location of the in-line resonator 140 along the pipe 130 does not affect the acoustic characteristics of the gas circulation device.

[0024] The controller 110 controls an actuator (not shown) actuating the valve 120. That is, the controller 110 controls timing of actuating the valve 120 relative to the phase of the pressure pulses (due to the pulse charging effect) near the valve such that to use the pressure pulses to enhance the volumetric efficiency of the compressor. If the valve 120 is the suction valve, the controller 110 controls the timing of actuating the valve 120 to have a maximum pressure value Δp added to the suction pressure, while the valve 120 is open (i.e., during the suction phase of the compressing cycle).

[0025] In another exemplary embodiment illustrated in Figure 4, the gas circulation device of an interface 101 includes a side branch resonator 150 in addition to the in-line resonator 140. Optionally, the side-branch resonator 150 may be connected to the in-line resonator 140 via a resonator valve 160. The resonator valve 160 may be switched to connect or to disconnect the side-branch resonator 150 to/from the pipe 130, depending on a composition of the gas (which composition affects the speed of sound in the gas and therefore the resonance frequency of the gas circulation device). The controller 110 may control the resonator valve 160.

[0026] In another exemplary embodiment illustrated in Figure 5, the gas circulation device of an interface 102 includes a side-branch pipe 170 instead of the in-line resonator 140. Optionally, the side-branch pipe 170 may be connected to the pipe 130 via a resonator valve 180. The resonator valve 180 may switched to connected or to disconnect the side-branch pipe 170 to/from the pipe 130, for example, depending on a composition of the gas (which composition affects the speed of sound in the gas and therefore the resonance frequency of the gas circulation device). The controller 110 may control the resonator valve 180.

[0027] Alternatively, in another exemplary embodiment illustrated in Figure 6, the gas circulation device of an interface 103 includes a side-branch resonator 200 attached to the pipe 130. Optionally, the side-branch resonator 200 may be connected to the pipe 130 via a resonator valve 210. The resonator valve 210 may be switched to connect or to disconnect the side-branch resonator 200 to/from the pipe 130, for example, depending on a composition of the gas (which composition affects the speed of sound in the gas, and, therefore, the resonance frequency of the gas circulation device). The controller 110 may control the resonator valve 210.

[0028] In another embodiment illustrated in Figure 7, a gas circulation device of an interface 104 includes an additional side-branch resonator 220 connected to the side-branch resonator 200. Optionally, the side-branch resonator 200 and/or the additional side-branch resonator 220 may be connected to pipe 130 and to the side-branch resonator 200, respectively via resonator valves 210 and 230, respectively. The resonator valves 210 and 230 may be switched to connect or to disconnect the side-branch resonator 200 and the additional side-branch resonator 220, respectively, depending on a composition of the gas (which affects the speed of sound in the gas, and, therefore, the resonance frequency of the gas circulation device). The controller 110 may control the resonator valve 210 and/or 230.

[0029] In another embodiment illustrated in Figure 8, the gas circulation device of the interface 105 has the side-branch resonator 200 connected to the volume bottle via a secondary pipe 240. A resonator valve 250 located on the secondary pipe 240 is switched depending on the composition of the gas.

[0030] In various embodiments illustrated in Figures 3-8 and other equivalent embodiments, it is executed a method 300 of using pulsations inherently generated outside but due to operating the reciprocating compressor, to enhance the volumetric efficiency of the compressor. As illustrated in Figure 9, the method 300 includes providing a gas circulation device between a valve of the reciprocating compressor and a volume bottle buffering the reciprocating compressor from an oil and gas plant, the gas circulation device being configured to have a resonance frequency substantially equal to a frequency of performing compression cycles in the reciprocating compressor, at S310. The method 300 further includes controlling the timing of actuating the valve to use pressure pulses inherently occurring in the gas circulation device due to the pulse charging effect, to enhance the volumetric efficiency of the reciprocating compressor, at S320.

[0031] In one embodiment, the providing S310 of method 300 may include adding a side-branch resonator or a side-branch pipe to a pipe connecting the valve to the volume bottle. In another embodiment, the providing S310 of method 300 may include switching one or more resonator valves connecting acoustic resonators to a pipe connecting the valve to the volume bottle.

[0032] An existing reciprocating compressor installation may be retrofitted to become able to use pulsations inherently generated during operation of the reciprocating compressor to enhance compressor's efficiency. Figure 10 is a flow chart of a method 400 for retrofitting the reciprocating compressor installation, according to an exemplary embodiment. The method 400 includes modifying a gas circulation device connecting an output or an input of the reciprocating compressor to the volume bottle, by adding at least one acoustic resonator to a pipe of the gas circulation device, to make the gas circulation device to have a resonance frequency substantially equal to a frequency of performing compression cycles in the reciprocating compressor, at S410. The method 400 further includes connecting a valve between the reciprocating compressor and the gas circulation device, to a controller configured to control timing of actuating the valve in order to use pressure pulsations occurring in the gas circulation device due to a pulse charging effect of the reciprocating compressor, to enhance a volumetric efficiency of the reciprocating compressor, at S420.

[0033] In one embodiment of the method 400, the at least one acoustic resonator may include an in-line acoustic resonator, a side-branch acoustic resonator or a side-branch pipe. In another embodiment, the method 400 may further include connecting the at least one acoustic resonator to the apparatus via a resonator valve.

[0034] The disclosed exemplary embodiments provide apparatuses (devices) and methods for using constructively the pressure pulses (i.e., the pulse charging effect) occurring around the reciprocating compressors due to the flow variation, to enhance the volumetric efficiency of the compressor. 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.

[0035] 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.

[0036] 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. An apparatus, comprising:

a gas circulation device that provides a path through which a gas to be compressed circulates between a reciprocating compressor and a volume bottle buffering the reciprocating compressor from an installation, the gas circulation device being configured to have a resonance frequency substantially equal to a frequency of performing compression cycles in the reciprocating compressor; and

a controller configured to control timing of switching a valve located between the reciprocating compressor and the gas circulation device in order to use constructively pressure pulsations occurring in the gas circulation device, to enhance a volumetric efficiency of the reciprocating compressor.

2. The apparatus of claim 1, wherein the gas circulation device comprises a pipe and an in-line resonator having an area larger than the pipe area, the pipe and the in-line resonator being arranged in-between the reciprocating compressor and the volume bottle.

3. The apparatus of claim 1 or claim 2, wherein the gas circulation device further comprises a side-branch resonator, arranged lateral to the in-line resonator wherein the side-branch resonator is connected to the in-line resonator via a resonator valve, the resonator valve being switched between being opened and being closed thereby connecting or disconnecting the side-branch resonator to the in-line resonator depending on a composition of the gas.

4. The apparatus of any preceding claim, wherein the gas circulation device comprises a pipe arranged between the reciprocating compressor and the volume bottle, and a side-branch pipe arranged lateral to the pipe, wherein the side-branch pipe is connected to the pipe via a resonator valve, the resonator valve being switched between being opened and being closed thereby connecting or disconnecting the side-branch pipe to the pipe depending on a composition of the gas.

5. The apparatus of any preceding claim, wherein the gas circulation device further comprises an additional side-branch resonator connected to the side resonator.

6. The apparatus of any preceding claim, wherein at least one of the side-branch resonator and the additional side-branch resonator is connected via a valve to the pipe or to the side-branch resonator, respectively, the valve being switched between being opened and being closed thereby connecting or disconnecting the side-branch pipe or the additional side-branch resonator thereof depending on a composition of the gas.

7. The apparatus of any preceding claim, wherein the gas circulation device comprises a pipe arranged between the reciprocating compressor and the volume bottle, and a side-branch pipe arranged lateral to the pipe, the side-branch pipe being connected to the pipe via a resonator valve, the resonator valve being switched between being opened and being closed thereby connecting or disconnecting the side-branch pipe to the pipe depending on a composition of the gas.

8. The apparatus of any preceding claim, wherein the valve is a suction valve and the controller controls the timing of actuating the valve to have a maximum pulsation pressure added to a suction pressure while the valve is open.

9. A method of using a pulse charging effect to enhance a volumetric efficiency of a reciprocating compressor, the method comprising:

providing a gas circulation device between a valve of the reciprocating compressor and a volume bottle buffering the reciprocating compressor from an instalation, the gas circulation device being configured to have a resonance frequency substantially equal to a frequency of performing compression cycles in the reciprocating compressor; and

controlling timing of actuating the valve to use constructively pressure pulses inherently occurring in the gas circulation device, to enhance the volumetric efficiency of the reciprocating compressor.

10. A method for retrofitting a reciprocating compressor installation in which an output or an input of a reciprocating compressor is buffered by a volume bottle from the rest of the installation, the installation being retrofitted to use a pulse charging effect of the reciprocating compressor to enhance a volumetric efficiency thereof, comprising:

modifying a gas circulation device connecting an output or an input of the reciprocating compressor to the volume bottle, by adding at least one acoustic resonator to a pipe of the gas circulation device, to make the gas circulation device to have a resonance frequency substantially equal to a frequency of performing compression cycles in the reciprocating compressor; and connecting a valve between the reciprocating compressor and the gas circulation device, to a controller configured to control timing of actuating the valve in order to use constructively pressure pulsations occurring in the gas circulation device, to enhance a volumetric efficiency of the reciprocating compressor.

Figure 1

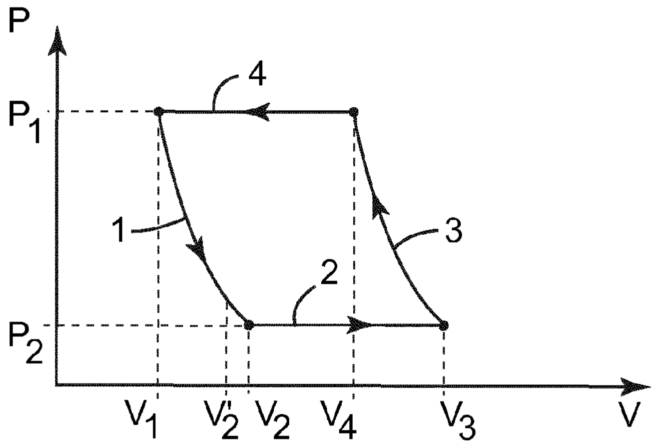


Figure 2
(Background Art)

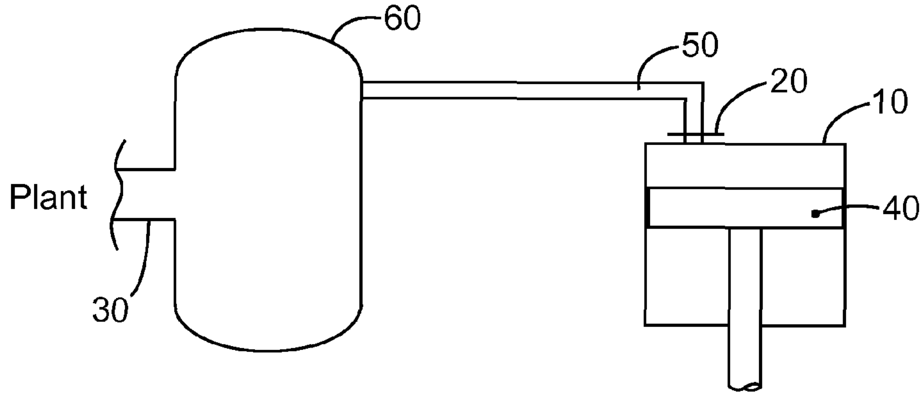


Figure 3

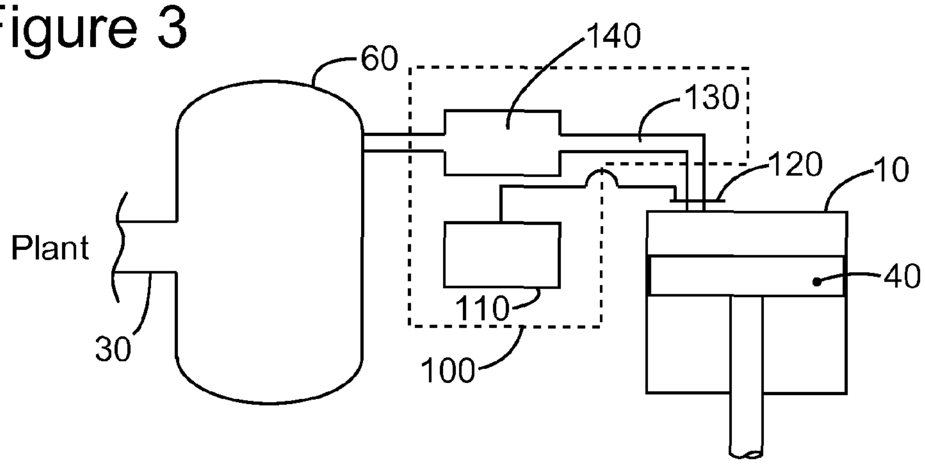


Figure 4

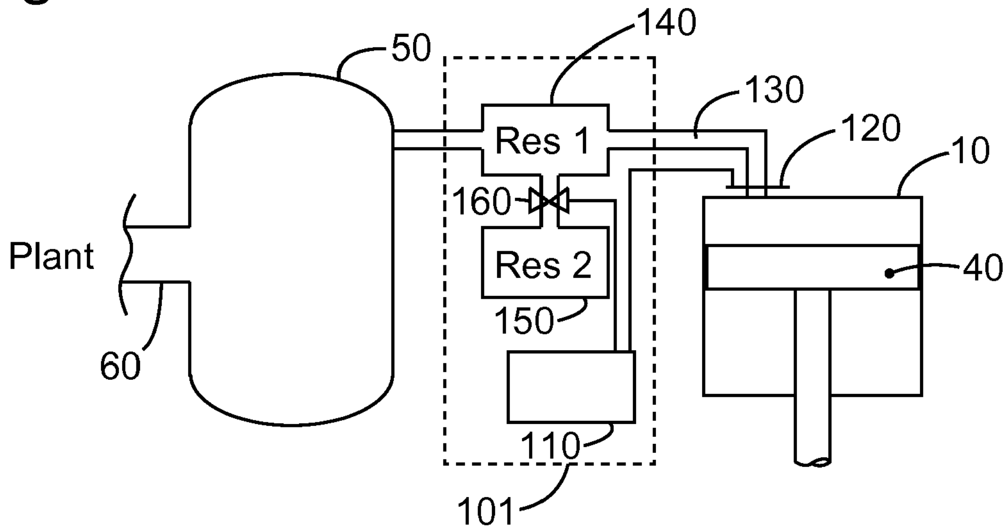


Figure 5

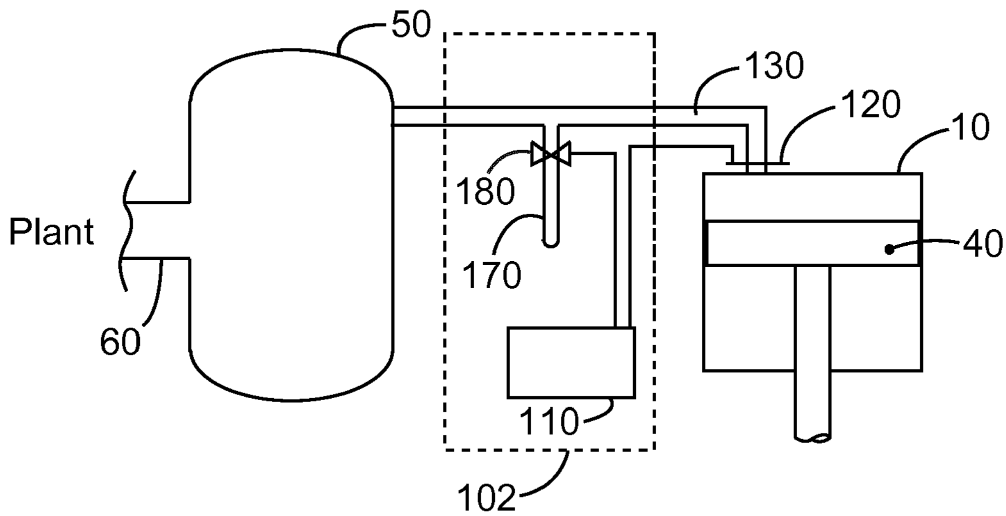


Figure 6

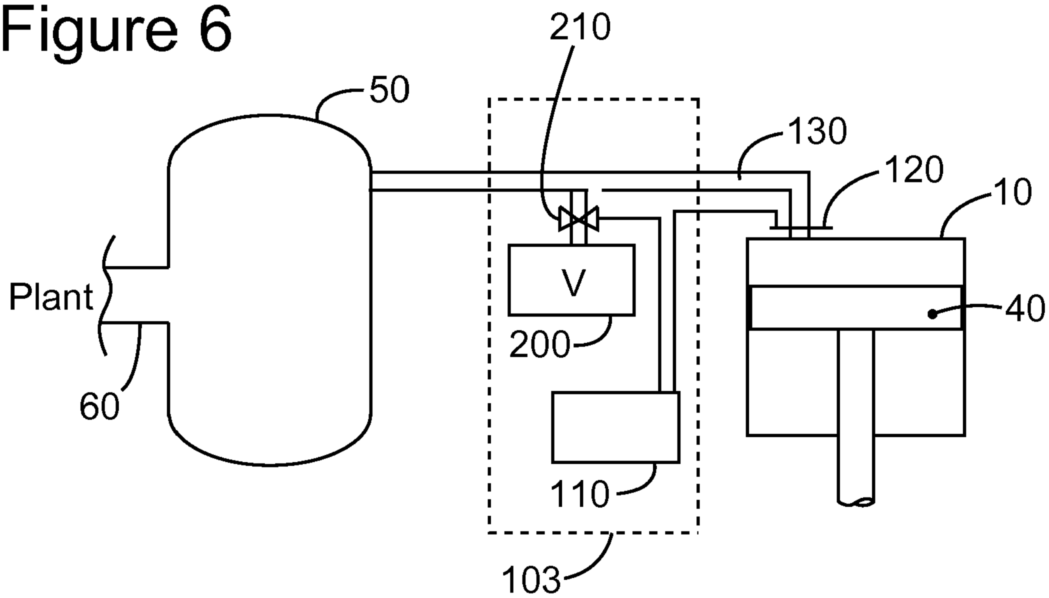


Figure 7

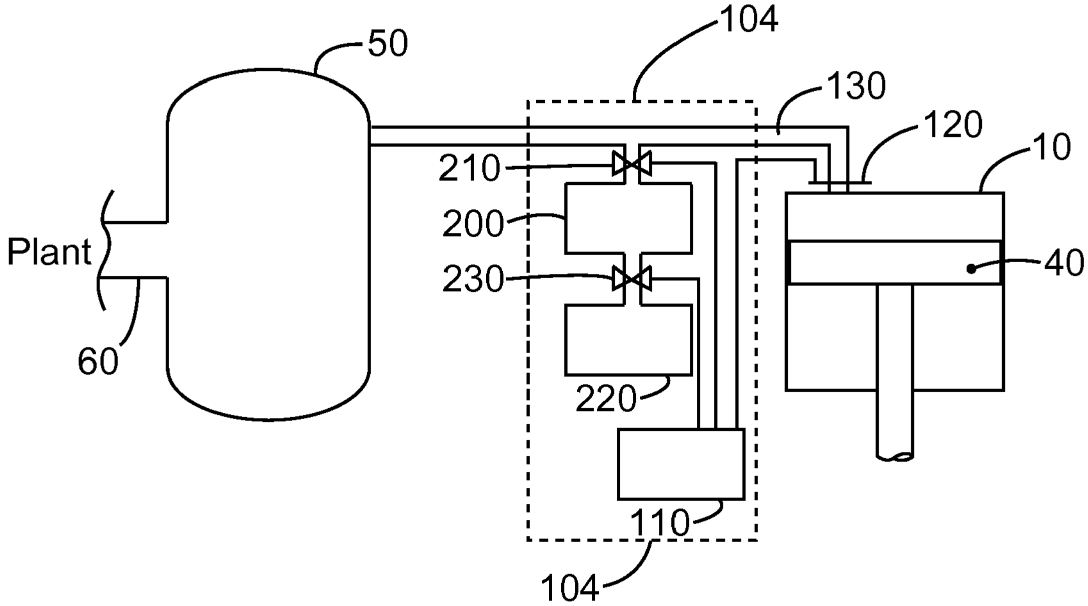


Figure 8

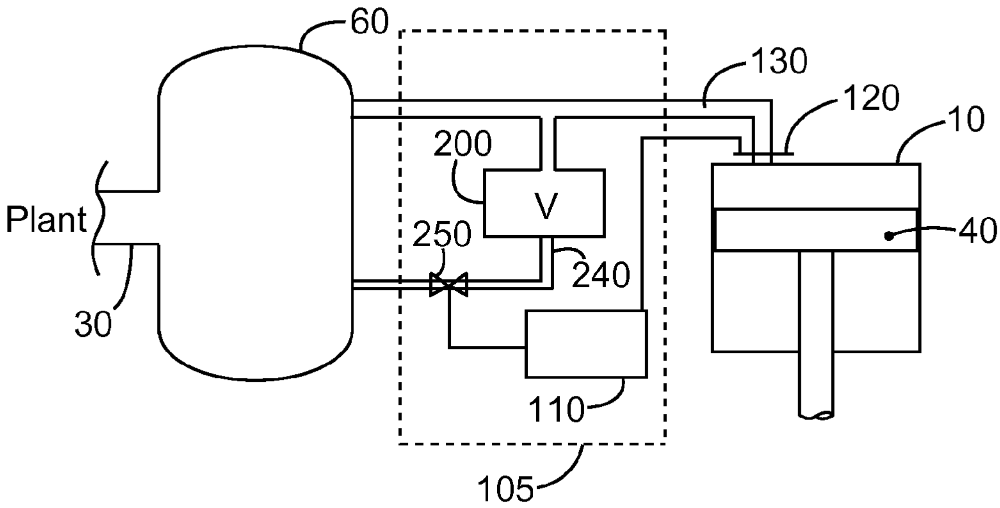


Figure 9

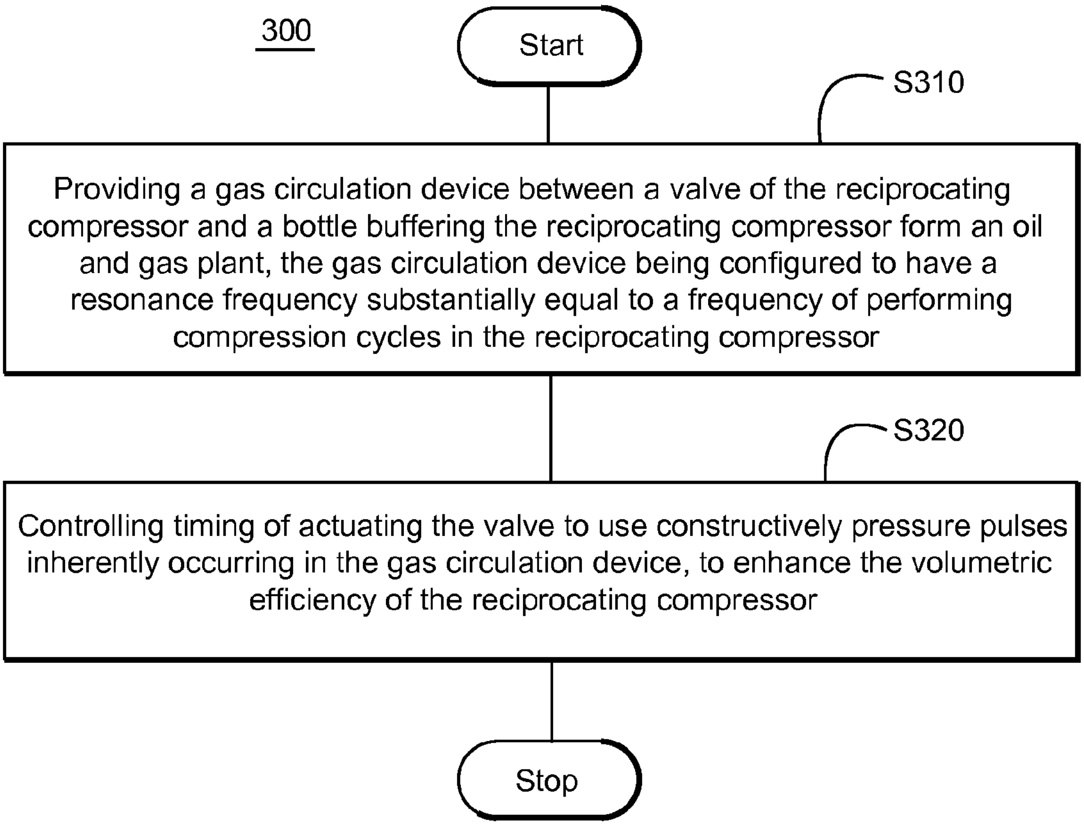
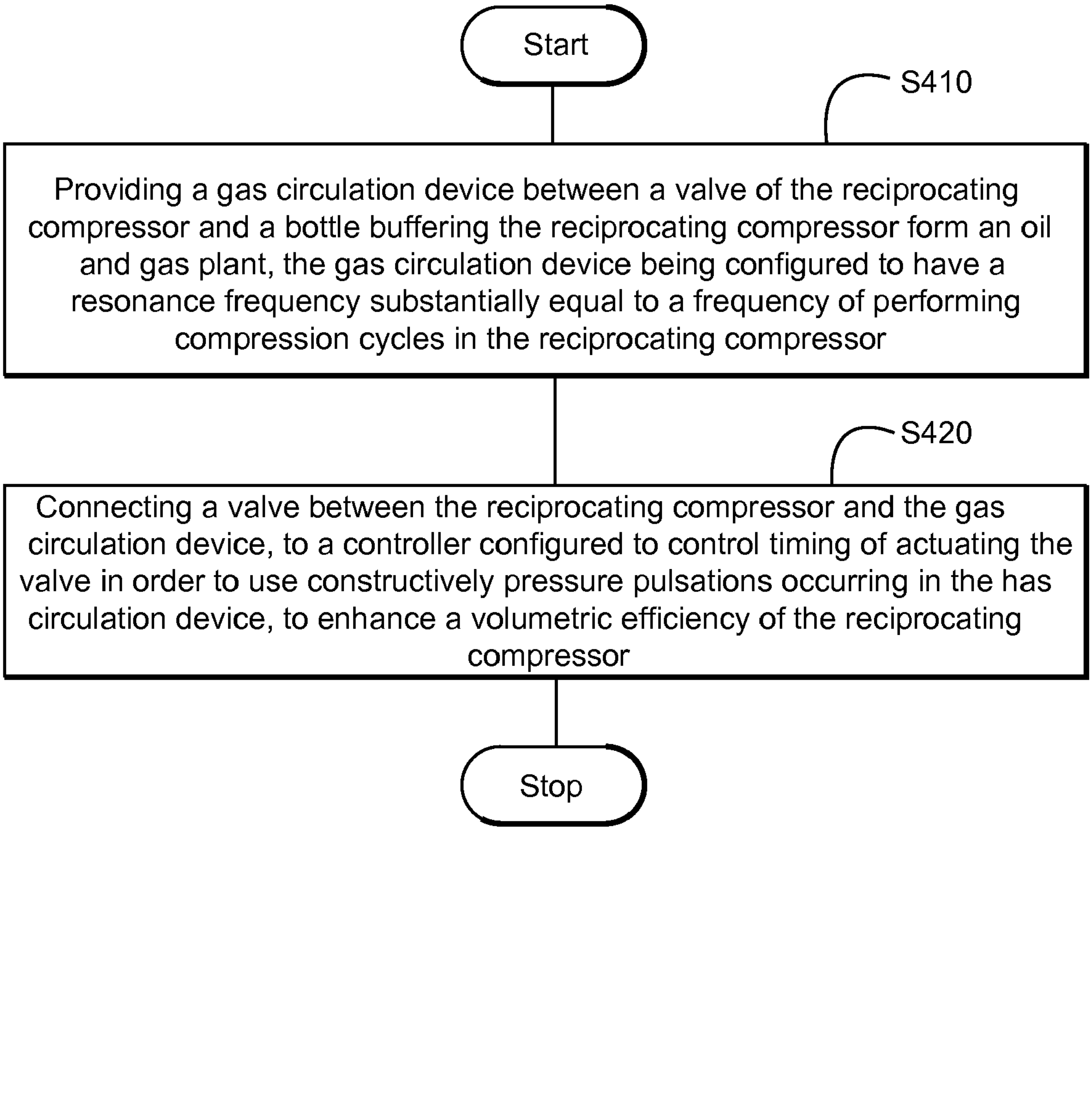


Figure 10


Start
S410
Providing a gas circulation device between a valve of the reciprocating compressor and a bottle buffering the reciprocating compressor form an oil and gas plant, the gas circulation device being configured to have a resonance frequency substantially equal to a frequency of performing compression cycles in the reciprocating compressor
S420
Connecting a valve between the reciprocating compressor and the gas circulation device, to a controller configured to control timing of actuating the valve in order to use constructively pressure pulsations occurring in the has circulation device, to enhance a volumetric efficiency of the reciprocating compressor
Stop