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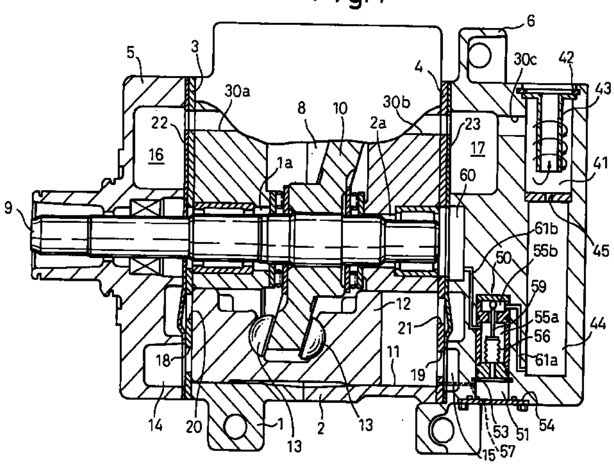
(54) Positive-displacement-type refrigerant compressor with a novel oil-separating and lubricating system

(57) A positive-displacement-type refrigerant compressor having a compression chamber, in which a refrigerant introduced from a suction system is compressed and discharged as a compressed refrigerant at a high pressure, and an oil-separating and lubricating system for lubricating an interior of the compressor by an oil component separated from the refrigerant, which has an oil-separating unit to separate the oil from the compressed refrigerant, an oil-storing chamber to store the separated oil, an oil-supply passage to supply the oil from the oil-storing chamber to the suction system, a valve assembly arranged in the oil supply passage for regulating an amount of flow of the oil from the oil-storing chamber to the suction system, which includes a first valve chamber, a movable valve actuating element in the first valve chamber to actuate a valve element to open and close a valve port which provides a fluid communication between the upstream and downstream of the oil-supply passage. The valve element moves in response to a movement of the valve actuating element and closes the valve port when the pressure introduced from the compression chamber and acting on the movable valve actuating element is overcome by an elastic restoring force acting on the movable valve actuating element.

Fig.1



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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention generally relates to a positive-displacement-type refrigerant compressor including a reciprocating type refrigerant compressor and a rotary type refrigerant compressor and, more particularly, relates to an oil-separating and lubricating system incorporated in the positive-displacement-type refrigerant compressor for the lubrication of internal various portions and movable elements of the positive-displacement-type refrigerant compressor by separating oil from a refrigerant at a high pressure and by supplying the separated oil to the portions and elements to be lubricated.

2. Description of the Related Art

[0002] In a positive-displacement-type refrigerant compressor mainly incorporated in a vehicle climate control system, lubrication of various internal portions and movable elements of the compressor is achieved by an oil, i.e., by an oil mist suspended in a gas-phase refrigerant which is compressed within the compressor. Therefore, when the compressed refrigerant containing and suspending therein the oil is delivered from the compressor to a refrigerating system in the climate control system, the oil is attached to an internal wall of an evaporator of the refrigerating system to result in an reduction in the heat exchanging efficiency of the evaporator. Thus, in the conventional refrigerating system, an oil separating unit is arranged in a high pressure gas pipe extending from the refrigerant outlet of the compressor to a condenser, and the separated oil is returned from the oil separating unit into the interior of the refrigerant compressor via a separate oil-return conduit. However, an arrangement of the oil separating unit in the gas pipe and an addition of the oil-return conduit to the refrigerating system make it cumbersome to assemble the refrigerating system of the vehicle climate control in a rather narrow assembling space in a vehicle. Further, the oil-return conduit is usually formed by a long pipe element having a small diameter, and accordingly, clogging easily occurs during the operation of the compressor. Therefore, there has been provided a refrigerant compressor provided with an oil-separating unit directly incorporated therein.

[0003] The oil-separating unit incorporated in the conventional refrigerant compressor is provided with an oil storing chamber formed in the compressor for storing an oil separated from a refrigerant in a high pressure region in the compressor, and an oil-return passage communicating the oil storing chamber with a low pressure region such as a crank chamber in the compressor for supplying the oil from the oil storing chamber to the low pressure region. The oil-return passage is provided with a valve unit arranged therein to control an amount of oil to be supplied into the low-pressure region in response to a change in the state of operation of the compressor.

[0004] For example, Japanese Unexamined Patent Publication (Kokai) No. 9-324758 (JP-A-9-324758) discloses a valve unit which functions to interrupt the oil-return passage during the running of the compressor, and to permit the oil to flow therethrough during the stopping of operation of the compressor.

[0005] Japanese Unexamined Patent Publication (Kokai) No. 6-249146 (JP-A-6-249146) discloses a valve unit used in a variable displacement type refrigerant compressor and operates in such a manner that when an oil separating chamber is kept at a high pressure during a large displacement operation of the compressor, a restricted amount of oil is permitted to pass through an oil-return passage via the valve unit, and when the oil separating chamber is kept at a low pressure during a small displacement operation of the compressor, a large amount of oil is permitted to pass through the oil-return passage via the valve unit.

[0006] Nevertheless, in the two conventional incorporated type oil separating systems of JP-A-9-324758 and JP-A-6-249146, no positive means to completely prevent the oil from being delivered from the interior of the compressor toward the associated refrigerating system is provided. Namely, since lubrication of various internal portions and movable elements of the refrigerant compressor must rely on mainly the oil suspended in the refrigerant returned from an external refrigerating system, at least when the refrigerant compressor is stopped, the amount of the oil supplied to the low pressure region in the compressor must be increased to prevent lack of lubricant at the start of operation of the refrigerant compressor. In this connection, even if the amount of oil delivered from the refrigerant compressor is small, delivery of the oil from the compressor into the external refrigerating system becomes a cause of preventing an increase in the heat exchanging efficiency in the refrigerating system depending on the rate of containment of an oil in the refrigerant. Moreover, when the compressor is stopped, if a large amount of oil is supplied to the low pressure region in the compressor, the oil remaining in the low pressure region is suddenly agitated due to re-starting of the compressor and accordingly, the oil is splashed so that compression of the oil, i.e., a liquid or oil compression occurs within the respective cylinder bores. Thus, shock and noise are generated in the interior of the refrigerant compressor.

SUMMARY OF THE INVENTION

[0007] Therefore, an object of the present invention is to obviate all defects encountered by the conventional oil separating and lubricating unit incorporated in a refrigerant compressor.

[0008] Another object of the present invention is to provide a positive-displacement-type refrigerant compressor internally provided with a novel oil-separating and lubricating system able to lubricate the interior of the compressor and to enhance the heat exchanging efficiency in a refrigerating system in which the compressor is incorporated.

[0009] A further object of the present invention is to provide a positive-displacement-type refrigerant compressor internally provided with an oil-separating and lubricating system having function to prevent occurrence of the oil compression even when the compressor is started.

[0010] In accordance with a broad aspect of the present invention, there is provided a positive-displacement-type refrigerant compressor including:

a suction system to receive a refrigerant, by suction, from an external refrigerating system,
a compressing mechanism having a compression chamber in which the refrigerant introduced from the suction system is compressed and discharged into a discharge chamber receiving the compressed refrigerant at a discharge pressure, and
an oil-separating and lubricating system for lubricating the interior of the positive-displacement-type refrigerant compressor by oil separated from the refrigerant,
wherein the oil-separating and lubricating system comprises:
an oil-separating unit accommodated in a high pressure region communicating with the discharge chamber to cause separation of the oil from the compressed refrigerant;
an oil-storing chamber accommodated in the high pressure region to store the oil separated by the oil-separating unit;
an oil-supply passage supplying the oil from the oil-storing chamber to the suction system;
a valve assembly disposed in a portion of the oil-supply passage for regulating an amount of flow of the oil from the oil-storing chamber to the suction system, the valve assembly comprising:
a first valve chamber having a substantial volume therein;
a second valve chamber arranged adjacent to the first valve chamber via a partition wall provided therebetween and fluidly communicating with an upstream side of the oil-supply passage;
a movable valve actuating element accommodated in the first valve chamber to be moved by an application of a pressure thereto against an elastic force, the movable valve actuating element defining outer and inner separate regions, one of which fluidly communicates with a downstream side of the oil-supply passage, and the other of which fluidly communicates with the compression chamber;
a valve element extending from the movable valve actuating element and opening and closing a valve port bored in the partition wall to provide a fluid communication between the upstream and downstream of the oil-supply passage, the valve element moving in response to a movement of the movable valve actuating element and closing the valve port when the pressure introduced from the compression chamber and acting on the movable valve actuating element is overcome by the elastic restoring force acting on the movable valve actuating element; and
a restriction arranged in a portion of the oil-supply passage for applying a flow restricting effect to the oil flowing through the oil-supply passage.

[0011] The movable valve actuating element may be either a bellows element accommodated in the first valve chamber or a combination of a spool valve element and an o-ring element.

[0012] In accordance with an embodiment, the valve assembly includes a first valve chamber accommodating therein a bellows element to define separate outer and inner regions, one of which fluidly communicates with a downstream side of the oil-supply passage, a second valve chamber arranged adjacent to the first valve chamber via a partition wall provided therebetween and fluidly communicating with an upstream side of the oil-supply passage, a valve element arranged to extend from the bellows element and being able to open and close a valve port bored in the partition wall in response to a movement of the bellows element which can be moved by a pressure introduced from the compression chamber, the valve element closing the valve port which, when opened, can provide a fluid communication between the upstream and downstream of the oil-supply passage when the pressure from the compression chamber acting on the bellows element is overcome by an elastic restoring force of the bellows element.

[0013] The oil-storing chamber is formed to have a volume suitable for storing substantially all of the oil filled in the interior of the compressor and circulated through the interior of the refrigerant compressor for the purpose of lubrication, and arranged to permit only the smallest possible amount of oil to flow out of the oil-storing chamber into the refrigerating system. Thus, the amount of the oil contained in the refrigerant is reduced to appreciably improve the heat exchanging efficiency of an evaporator in the refrigerating system. Therefore, the interior of the compressor, i.e., various internal portions and movable elements of the compressor can be lubricated by the oil stored in the oil-storing chamber and circulated through the suction system of the compressor and the oil-separating unit during the operation of the compressor. When the operation of the compressor is stopped, the supply of the oil to the lubricated portions and the movable elements of the compressor due to the circulation of the oil is automatically stopped.

Accordingly, the amount of oil remaining in the suction system of the compressor, which includes a crank chamber, can be kept small to prevent the occurrence of oil compression when the compressor is started. Further, when the compressor is started, the oil stored in the oil-storing chamber can be quickly supplied to the lubricated portions and the movable elements of the compressor due to an immediate start of circulation of the oil through the suction system, and the oil-separating and lubricating system.

[0014] Moreover, since the valve assembly includes the valve element which moves in association with an expanding and contracting movement of the bellows element to open and close the valve port providing a fluid communication between the upstream and downstream of the oil-supplying passage extending through the first and second valve chambers, and since the valve assembly requires no sealing means for fluidly sealing any of the movable valve element and the bellows element, the opening and closing movement of the valve element can be stable and accurate enough for guaranteeing the performance of the valve assembly.

[0015] The restriction disposed in the oil-supplying passage can limit an amount of oil flowing from the oil-storing chamber into the suction system.

[0016] The valve port may be provided so as to serve both as an aperture cooperating with the valve element to adjustably change the amount of oil passing through the aperture and a flow restriction to limit the amount of oil flowing through the oil-supplying passage from the oil-storing chamber to the suction system of the compressor. Thus, the construction of the valve assembly can be simplified.

[0017] Alternately, in accordance with another embodiment of the present invention, the valve assembly may include a first valve chamber fluidly communicating with the downstream side of the oil-supplying passage and having an inner wall, a spool valve element disposed in the first valve chamber and having an outer face facing the inner wall of the first valve chamber via a small gap, an o-ring element deformably disposed in the small gap and fitted in a pair of annular recesses formed in the inner wall of the first valve chamber and the outer face of the spool valve element to movably support the spool valve element, a second valve chamber arranged adjacent to the first valve chamber via a partition wall provided therebetween and fluidly communicating with an upstream side of the oil-supply passage, a valve element arranged to extend from the valve spool element and being able to open and close a valve port bored in the partition wall in response to a movement of the valve spool element which can be moved by a deformation of the o-ring which is caused by a pressure introduced from the compression chamber, and a restriction arranged in a portion of the oil-supply passage, the valve element closing the valve port which, when opened, can provide a fluid communication between the upstream and downstream sides of the oil-supply passage when the pressure from the compression chamber acting on the valve spool element is overcome by an elastic restoring force of the o-ring.

[0018] The above-mentioned valve assembly employing the valve spool element and the o-ring may be simpler in its construction than the afore-mentioned valve assembly employing the bellows element and accordingly, can be less expensive.

[0019] Preferably, a pressure-introduction passage for introducing the pressure in the compression chamber into a position acting on the valve element is provided with a flow restriction function therein. Thus, when the positive-displacement-type refrigerant compressor employs reciprocating pistons to compress the refrigerant, the pressure acting on the valve element can be maintained substantially at an average pressure of the pressures prevailing in the compression chamber and hardly changes.

[0020] On the other hand, when the positive-displacement-type refrigerant compressor is a rotary type refrigerant compressor, the pressure acting on the valve element can be an intermediate pressure of pressures prevailing in the compression chamber. Thus, the movement of the valve element cooperating with the valve port can be very stable.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] The above and other objects, features, and advantages of the present invention will be made more apparent from the ensuing description of the preferred embodiments thereof with reference to the accompanying drawings wherein:

Fig. 1 is a longitudinal cross-sectional view of a positive-displacement-type refrigerant compressor, i.e., a swash plate operated double-headed piston type refrigerant compressor with an oil-separating and lubricating system, according to an embodiment of the present invention;

Fig. 2 is an enlarged cross-sectional view of a valve assembly adapted for use in the oil-separating and lubricating system of the compressor of Fig. 1, illustrating a state where a valve port is opened;

Fig. 3 is a similar view to Fig. 2, illustrating a state where the valve port is closed by a valve element;

Fig. 4 is an enlarged cross-sectional view of a different valve assembly adapted for use in the oil-separating and lubricating system of the compressor of Fig. 1, illustrating a state where a valve port is opened by a valve element;

Fig. 5 is a similar view to Fig. 4, illustrating a state where the valve port is closed by the valve element;

Fig. 6 is an enlarged cross-sectional view of a further different valve assembly adapted for use in the oil-separating and lubricating system, illustrating a state where a valve port is closed by the valve element;

Figs. 7A through 7C are schematic views illustrating opened and closed conditions of the valve port of the valve assembly of Fig. 6, in relation to an elastic deformation of an o-ring incorporated in the valve assembly of Fig. 6;

Figs. 8A and 8B are schematic views illustrating two modified constructions of the valve assembly of Fig. 6; and,

Fig. 9 is a cross-sectional view of a scroll type refrigerant compressor, i.e., a typical rotary type refrigerant compressor, provided with an oil-separating and lubricating system therein, according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0022] Referring to Fig. 1, a double-headed piston incorporated reciprocating type refrigerant compressor is provided with a pair of axially combined cylinder blocks 1 and 2 having later-described five cylinder bores on axially left and right sides of the combined cylinder blocks. The combined cylinder blocks 1 and 2 have axially front and rear ends closed by a front housing 5 and a rear housing 6, via a front valve plate 3 and a rear valve plate 4, respectively. The front housing 5, the front cylinder block 1, the rear cylinder block 2 and the rear housing 6 are gas-tightly combined together by several long screw bolts (not shown in Fig. 1). The connecting portion of the combined front and rear cylinder blocks 1 and 2 is provided with a crank chamber 8 formed therein to receive a swash plate (a cam plate) 10 fixedly mounted on a drive shaft 9 which is rotatably supported by the combined cylinder blocks 1 and 2, and axially extends through a central bores 1a and 2a of the combined cylinder blocks 1 and 2. The swash plate 10 is thus rotated together with the drive shaft 9 about an axis of rotation of the drive shaft 9.

[0023] The axially aligned five cylinder bores 11 on the left and right sides of the combined cylinder blocks 1 and 2 are arranged in parallel with one another with respect to and circumferentially spaced apart from one another around the axis of rotation of the drive shaft 9.

[0024] Double-headed pistons 12 are slidably fitted in the cylinder bores 11 on the axially left and right sides of the cylinder blocks 1 and 2, and each of the double-headed pistons 12 is engaged with the swash plate 10 via a pair of semispherical shoes 13, 13.

[0025] The front and rear housings 5 and 6 are internally provided with suction chambers 14 and 15 formed in a radially outer region of the interior of the respective housings 5 and 6, and discharge chambers 16 and 17 formed in a radially inner region of the interior of the front and rear housings 5 and 6. The front and rear valve plates 3 and 4 are provided with suction ports 18, 19 formed therein to permit the refrigerant to be sucked from the respective suction chambers 14 and 15 into the respective cylinder bores 11 on the left and right sides. The front and rear valve plates 3 and 4 are also provided with discharge ports 20, 21 formed therein to permit the high pressure refrigerant after compression to be discharged from the respective cylinder bores 11 on the left and right sides toward the discharge chambers 16 and 17. Suction valves (not shown) are arranged in respective boundaries between the front and rear ends of the combined cylinder blocks 1 and 2 and the front and rear valve plates 3 and 4 to openably close the suction ports 18, 19, and discharge valves (not shown) are arranged in respective boundaries between the front and rear valve plates 3 and 4 and the front and rear housings 5 and 6 to openably close the discharge ports 20 and 21 and to be supported by valve retainers 22 and 23.

[0026] As best shown in Fig. 1, the discharge chambers 16 and 17 of the front and rear housings 1 and 2 are provided with partially radially extending portions therein, which are fluidly connected to one another by discharge passages 30a and 30b formed in the combined cylinder blocks 1 and 2, and are fluidly connected to a delivery passage 30c formed in the rear housing 6, and the delivery passage 30c is fluidly connected to an outlet port (not shown in Fig. 1) for delivering the compressed refrigerant into an external refrigerating system via an oil-separating mechanism which is also formed in the rear housing 6.

[0027] The above-mentioned oil-separating mechanism constitutes a part of an oil-separating and lubricating system, and the oil-separating mechanism includes an oil-separating chamber 41 formed as a cylindrical bore formed in the rear housing 6 to have an inner bottom. The oil-separating chamber 41 fluidly communicates with the above-mentioned delivery passage 30c and receiving therein a flanged oil-separating cylinder 43 which is attached to an uppermost position of the oil-separating chamber 41 by means of a snap ring 42. An oil-storing chamber 44 is arranged below the oil-separating chamber 41 for receiving an oil from the chamber 41. The oil-storing chamber 44 is formed to have sufficient volume enough to store all of the oil which is preliminarily filled into the interior of the compressor during the assembly of the compressor, and for surely circulating all of the filled oil through various pressure regions in the interior of the compressor for the purpose of lubricating many portions such as cylinder bores 11 and opposite faces of the swash plate 10, and movable elements of the compressor such as double-headed pistons 12, shoes 13, and various radial and thrust bearings. The fluid communication between the oil-separating chamber 41 and the oil-storing chamber 44 is provided by an oil hole 45 formed in the bottom of the oil-separating chamber 41.

[0028] The oil-separating and lubricating system is further provided with a valve assembly 50 formed as a differential pressure type valve assembly and seated in a bottomed bore 51 formed in the rear housing 6. As shown in Figs. 2 and 3, the valve assembly 50 includes a framework 52 formed to be fitted in the bottomed bore 51 of the rear housing 6. The framework 52 is formed by two separate frames 52a and 52b, and a plate cap 52d which are fixedly seated in position within the bore 51 by means of a snap ring 53. An opening of the bottomed bore 51 is closed by a plate-like lid 54. The framework 52 of the valve assembly 50 is provided with a hollow first valve chamber 55a and a hollow second valve chamber 55b separated by a partition plate 52c, and the first valve chamber 55a receives a bellows element 56 capable of expanding and contracting therein and having one end fixed to the frame 52b and the other end sealingly connected to a flange member. The bellows element 56 is provided as a movable valve actuating element, and the interior of the bellows element 56 is formed as a pressure sensing chamber communicating with a cylindrical pressure chamber 51a formed in the bottomed bore 51 below the frame 52b. Namely, a small hole 72 is formed in the frame 52b to provide a fluid communication between the pressure sensing chamber of the bellows element 56 and the cylindrical pressure chamber 51a. The cylindrical pressure chamber 51a also communicates with a compression chamber in a predetermined one of the cylinder bores 11, via a pressure-introducing passage 57 which extends through the rear housing 6 from the above-mentioned cylindrical pressure chamber 51a to the predetermined cylinder bore 11. The pressure-introducing passage 57 is formed as a passage having a small diameter, so that it can function as a flow restriction to make a pressure flat when it is introduced from the compression chamber of the cylinder bore 11 into the cylindrical pressure chamber 51a.

[0029] The flange plate connected to the other end of the bellows element 56 is connected at its central position to a valve element 59 extending in a direction corresponding to a direction in which the bellows element 56 expands. An upper portion of the valve element 59 extends through a through bore formed as a valve port 58 in the partition plate 52c, and has a spherical valve 59a at an extreme end thereof positioned in the second valve chamber 55b. The valve assembly 50 is mounted in the bottomed bore 51 so as to be hermetically sealed by suitable sealing members 70 such as o-rings fitted in grooves recessed in the outer circumference of the framework 52.

[0030] The rear housing 6 is provided with a counterbore 60 centrally formed therein, which fluidly communicates with the crank chamber 8 via the central bore 2a of the combined cylinder blocks 1 and 2. The rear housing 6 is further provided with an oil passage 61a extending between the oil-storing chamber 44 and the second valve chamber 55b of the valve assembly 50 received in the bottomed bore 51, and an additional oil passage 61b extending between the first valve chamber 55a and the above-mentioned counter-bore 60. Thus, the counter-bore 60 is fluidly communicated with the oil-storing chamber 44 through the oil passages 61a and 61b and the valve assembly 50, so that the oil stored in the oil-storing chamber 44 can be supplied to the counter-bore 60, and additionally to the central bore 2a and the crank chamber 8. Namely, the oil passages 61a and 61b are provided as upstream side and downstream side oil-supplying passages, respectively, so that a circulating oil lubrication passageway is formed by which the oil to lubricate the interior of the compressor is basically circulated through the oil-storing chamber 44, the upstream side oil passage 61a, the valve assembly 50, the downstream side oil passage 61b, the counter-bore 60, the central bore 2a, the crank chamber 8, the discharge chambers 16, 17, and the oil-separating chamber 41.

[0031] As best shown in Figs. 2 and 3, in a preferred embodiment, an oil restriction 62 is arranged in the oil passage 61a for restricting an amount of supply of the lubricating oil from the oil-storing chamber 44 into the crank chamber 8 constituting a part of the suction system of the compressor.

[0032] When the positive-displacement-type refrigerant compressor incorporating the oil-separating and lubricating system of Figs. 2 and 3 is driven by an application of a drive power from an external drive source, i.e., a vehicle engine to the drive shaft 9, the drive shaft 9 is rotated together with the swash plate 10, and the double-headed pistons 12 engaged with the swash plate 10 are reciprocated in the corresponding cylinder bores 11. Therefore, the refrigerant is sucked from the suction chambers 14, 15 into the cylinder bores 11 and compressed by the pistons 12. The compressed refrigerant is discharged by the pistons 12 from the compression chambers within the cylinder bore 11 toward the discharge chambers 16, 17. When the compressed refrigerant is discharged into the discharge chambers 16, 17, it is further introduced into the oil-separating chamber 41 via the discharge passages 30a and 30b and the delivery passage 30c. When the compressed refrigerant is introduced from the delivery passage 30c into the oil-separating chamber 41, the compressed refrigerant is forcedly rotated around the oil-separating cylinder 43 by the cylindrical inner wall of the oil-separating chamber 41, as shown by arrows in Fig. 1, and is introduced into the interior of the flanged oil-separating cylinder 43 via an opening thereof. The compressed refrigerant is further delivered from the interior of the oil-separating cylinder 43 toward an external refrigerating system via a delivery port (not shown in Fig. 1) of the compressor.

[0033] During the rotary movement of the compressed refrigerant in the oil-separating chamber 41, the oil component suspended in the compressed refrigerant is effectively separated from the refrigerant due to a centrifugal force acting on the oil component, and the separated oil flows down to the bottom of the oil-separating chamber 41, and further into the oil-storing chamber 44 via the oil hole 45. At this stage, it should be understood that due to the oil separation from the refrigerant in the oil-separating chamber 41, the refrigerant containing less oil component therein is delivered from the delivery port of the compressor into the external refrigerating system. Namely, a rate of oil contained in a unit weight of refrigerant is reduced within the oil-separating chamber 41 before the compressed refrigerant gas is delivered from the delivery port. Thus, the compressed refrigerant containing less amount of oil component can be effectively used as a heat-exchange-medium in the refrigerating system.

[0034] Further, when oil separation is conducted by the oil-separating mechanism within the oil-separating chamber 41, pulsation in the pressure of the compressed refrigerant can be physically suppressed. Thus, the compressed refrigerant under a relatively stable pressure can be delivered from the compressor to the external refrigerating system, so that any adverse affect, such as vibration and noise, is not provided by the refrigerating system.

[0035] During the operation of the refrigerant compressor, a very high pressure prevails in the cylindrical pressure chamber 51a and the interior of the bellows element 56 and through the pressure-introducing passage 57 which extends between the predetermined one of the cylinder bores 11 and the cylindrical pressure chamber 51a. At this stage, the cylindrical pressure chamber 51a and the interior of the bellows element 56 is maintained at a relatively high and steady pressure intermediate between the peak discharge pressure and the suction pressure within the cylinder bore 11, due to the flow restriction effect of the narrow pressure-introducing passage 57.

[0036] When a high pressure prevails in the interior of the bellows element 56, the bellows element 56 is extended by overcoming a force due to an addition of a pressure prevailing in the first valve chamber 55a which communicates with the suction region of the compressor, i.e., the counter-bore 60 via the downstream side oil passage 61b and the elastic restoring force of the bellows element 56 (the contracting force of the element 56). Therefore, the valve element 59 and the spherical valve 59a are moved together, by the bellows element 56, to keep the valve port 58 at its opened state as shown in Fig. 2. Accordingly, the upstream and downstream oil passages 61a and 61b are connected to one another via the second valve chamber 55b, the opened valve port 58 and the first valve chamber 55a, so that the oil stored in the oil-storing chamber 44 flows through these oil passages into the counter-bore 60 in the rear housing 6, and the amount of flow of the oil is restricted and kept constant by the flow restriction 62 in the upstream side oil passage 61a. The oil further flows from the counter-bore 60 into the crank chamber 8 via the central bore 2a of the rear cylinder block 2 to lubricate many inner portions of the compressor such as the cylinder bores 11, and the movable elements such as the double-headed pistons 12, various bearings, the swash plate 10 and, the shoes 13 and is eventually mixed with the refrigerant within the suction pressure region. Thus, during the operation of the compressor, a controlled amount of oil component is constantly circulated through the oil-storing chamber 44, the crank chamber 8, and the oil-separating chamber 41 while lubricating the interior of the compressor.

[0037] It should be understood that at the initial stage of the starting of the operation of the compressor, since the valve port 58 is not still opened by the valve element 59, a discharge pressure in the oil-separating chamber 41 acts in the second valve chamber 55b of the valve assembly 50 via the oil stored in the oil-storing chamber 44 and the upstream side oil passage 61a so as to apply a resistance against the opening movement of the valve element 59. Nevertheless, a pressure receiving area of the spherical valve 59a of the valve element 59 is rather smaller than that of the bellows element 56 on which the pressure introduced from the compression chamber via the pressure-introducing passage 57 acts to expand the bellows element 56. Thus, the opening of the valve port 58 of the valve assembly 50 can be easily and surely achieved immediately after the starting of the operation of the refrigerant compressor.

[0038] When the operation of the refrigerant compressor is stopped, the pressure prevailing in the cylindrical pressure chamber 51a and the interior of the bellows element 56 through the pressure-introducing passage 57 is reduced to a pressure level substantially equal to the suction pressure of the compressor and, accordingly, the bellows element 56 of the valve assembly 50 contracts due to the elastic restoring force thereof to move the valve element 59 and the spherical valve 59a to the closing position closing the valve port 58, as shown in Fig. 3. Therefore, the circulation of the oil through the oil-storing chamber 44, the crank chamber 8 and the oil-separating chamber 41 is stopped. Accordingly, the supply of oil to the crank chamber 8 is automatically stopped to prevent an excessive amount of oil from remaining in the crank chamber 8. Thus, when the operation of the refrigerant compressor is again started, oil-compression within the cylinder bores 11 does not occur. Moreover, as soon as the operation of the refrigerant compressor is started, the circulation of the oil from the oil-storing chamber 44 to the oil-separating chamber 4 through the crank chamber 8 is quickly started to lubricate the interior of the compressor. It should be understood that when the operation of the refrigerant compressor stops for a long continuous time, the bellows element 56 of the valve assembly 50 is kept at its contracted condition due to the elastic restoring force thereof while maintaining the valve element 59 at its closed position closing the valve port 58. Thus, a constant stoppage of supply of the oil from the oil-storing chamber 44 to the crank chamber 8 can be prevented by the valve assembly 50.

[0039] In a modified embodiment, it is possible to remove the flow restriction 62 arranged in the upstream side oil passage 61a if the valve port 58 formed in the partition plate 52c is provided with a flow restriction function by forming it as a narrow passage having an increased length. Thus, the construction of the oil-separating and lubricating system incorporated in the positive-displacement-type refrigerant compressor can be simplified.

[0040] Figure 4 shows a different valve assembly 80 incorporated in an oil-separating and lubricating system assembled in a refrigerant compressor according to the present invention. The valve assembly 80 shown in Fig. 4 is kept at a condition where a valve port 88 is opened. The valve assembly 80 is provided with a framework 82 formed by a cylindrical frame 82a and a lid-like frame 82b. The framework 82 is provided with hollow first and second valve chambers 85a and 85b separated by a partition plate 82c in which the valve port 88 in the form of a through-bore is formed. The first valve chamber 85a receives therein a bellows element 86 expanding and contracting in a longitudinal direction thereof. One end of the bellows element 86 is attached to the partition plate 82c and the other end of the bellows element 86 is closed by an end plate member. An outer region of the first valve chamber 85a surrounding the bellows element 86 is fluidly connected to a compression chamber within a predetermined one of the cylinder bores 11 via a cylindrical pressure chamber 51a and a pressure-introducing passage 57 which are similar to those of the afore-mentioned embodiment of Figs. 2 and 3. A valve element 89 is arranged to extend from the end plate of the bellows element 86 through the interior of the bellows element 86 and the valve port 88 into the second valve chamber 85b in which the valve element 89 has a spherical valve 89a at its extreme end to open and close the valve port 88. The second valve chamber 85b is fluidly connected to an oil passage 61a, i.e., an upstream side passage connected to the oil-storing chamber 44 (see Fig. 1), and the interior of the bellows element 86 is fluidly connected to a downstream side oil passage 61b extending toward the counter-bore 60 (Fig. 1) of the rear housing 6 of the refrigerant compressor.

[0041] Thus, the operation principle of the valve assembly 80 of Fig. 4 is substantially similar to that of the valve assembly 50 of the embodiment of Figs. 2 and 3 and is different only in that the valve element 89 and the spherical valve 89a are moved from its opened position to open the valve port 88 shown in Fig. 4 to its closed position to close the valve port 88 when the bellows element 86 is expanded by an elastic restoring force thereof in response to a reduction in a pressure prevailing in the cylindrical pressure chamber 51a and the cylindrical region of the first valve chamber 85a surrounding the bellows element 86 via the pressure-introducing passage 57. Therefore, the detailed description of the operation of the valve assembly 80 is omitted for the sake of brevity.

[0042] Figures 5 and 6 illustrate a different embodiment of a valve assembly accommodated in an oil-separating and lubricating system for a positive-displacement-type refrigerant compressor.

[0043] The valve assembly 90 of the present embodiment is similarly provided with a framework 92 defining therein a first valve chamber 95a and a second valve chamber 95b separated by a partition plate 92c. The first valve chamber 95a receives therein a valve spool 94 to be movable toward and away from the second valve chamber 95b. The valve spool 94 is provided as a movable valve actuating element to actuate a movement of a later-described valve element. A small annular gap is provided between a cylindrical outer wall of the valve spool 94 and a cylindrical inner wall of the first valve chamber 95a. The valve spool 94 is provided with a circularly extending v-shape groove R1 formed in the cylindrical outer wall, which is arranged to substantially confront a circularly extending v-shape groove R2 formed in the cylindrical inner wall of the first valve chamber 95a, and an o-ring 96 is arranged in the annular gap and received in the confronting v-shape grooves R1 and R2. Thus, the o-ring 96 supports the valve spool 94 in position within the first valve chamber 95a. The o-ring 96 further provides a fluid separation in the first valve chamber 95a between a pressure chamber 97 facing one of the opposite faces of the valve spool 94 and fluidly connected to the pressure-introducing passage 57 and an oil chamber region facing the other of the opposite faces of the valve spool 94. The valve spool 94 is provided with an integral valve element 99 which extends longitudinally through the oil chamber region and a valve port 98 bored in the partition plate 92c into the second valve chamber 95b. The valve element 99 has a spherical valve 99a provided at an extreme end thereof within the second valve chamber 95b, so that the spherical valve 99a of the valve element 99 opens and closes the valve port 98 due to the longitudinal movement of the valve element 99 actuated by the valve spool 94 movable in a direction parallel with the inner wall of the first valve chamber 95a.

[0044] In the embodiment of Figs. 5 and 6, when the spherical valve 99a is moved to its opened position to open the valve port 98, the o-ring 96 is forcedly and elastically deformed within the v-shape grooves R1 and R2. Thus, the elastic restoring force of the o-ring 96 is used for moving the spherical valve 99a to its position to close the valve port 98 via the valve spool 94 and the valve element 98. Thus, the construction of the valve assembly 90 can be simpler than the previous embodiments of Figs. 2 and 3, and Fig. 4, employing a bellows element 56 and 86.

[0045] Further, in the embodiment of Fig. 5, the o-ring 96 received in the v-shape grooves R1 and R2 does not come into contact with each of the cylindrical walls of the valve spool 94 and the framework 92 during the movement of the valve spool 94 and, accordingly, the movement of the valve spool 94 moving the spherical valve 99a of the valve element 99 can be free from any resistance due to a contacting movement. As a result, the opening and closing movement of the spherical valve 99a can be always smooth.

[0046] Figures 7A through 7C illustrate a relationship between the opening and closing condition of the port 98 and the deforming condition of the o-ring 96 in relation to the movement of the valve spool 94 of the valve assembly 90.

[0047] In Figs. 7A through 7C, the three different levels of deformation of the o-ring 96 shown by level 0, level 1 and level 2, indicate a first condition in which no torsional load is applied to the o-ring 96, a second condition in which a preliminarily torsional load is applied to the o-ring to obtain an elastic restoring force to close the valve port 98, and a third condition in which a maximum load is applied to the o-ring 96 to place the valve port 98 in a completely opened condition, respectively. Particularly, Figs. 7B and 7C illustrate the spherical valve 99a attached to the extreme end of the valve element 99 moved to its closing position to close the valve port 98 and moved to its opened position to open the valve port 98. Nevertheless, Fig. 7A illustrates an imaginary position of the spherical valve 98a if the torsional load is removed from the o-ring 96. As can be understood from the illustrations of Figs. 7B and 7C, the o-ring 96 is deformed to receive a torsional load even when the spherical valve 99a is moved to its closing position to close the valve port 98.

[0048] Figures 8A and 8B illustrate two modified constructions of the valve assembly.

[0049] In the valve assembly 90A of Fig. 8A, an elastic element, i.e., a spring 99b, and a rest 99c are additionally arranged in the second valve chamber 95b to apply a spring force urging the spherical valve 99a toward its closing position to close the valve port 98. In this case, the o-ring 96 does not need to be preliminarily deformed to exhibit a restoring force urging the spherical valve 99a to its closing position to close the valve port 98. Namely, the o-ring 96 is received in the annular V-shape grooves R1 and R2 of the valve spool 94 and the framework 92 in such a manner that when the spherical valve 99a of the valve element 99 is in its closing position, the two annular V-shape grooves R1 and R2 are substantially in registration with one another. Thus, the o-ring 96 hermetically seals between the portion of the first valve chamber 95a connected to the oil passage 61b and the pressure chamber 97 of the first valve chamber 97 but is not subjected to deformation during the closing of the valve port 98 by the spherical valve 99a of the valve element 99. More specifically, the o-ring 96 is deformed to receive a torsional load only when the valve spool 94 and the spherical valve 99a of the valve element 99 are moved to the position to open the valve port 98 against the spring force of the spring 99b. Thus, the physical durability of the o-ring 96 can be appreciably increased to ensure a long operation life of the o-ring 96.

[0050] In the valve assembly 90B of Fig. 8B, an elastically movable reed valve 100 is used for opening and closing the valve port 98, and the valve element 99A integral with the valve spool 94 is used for moving the reed valve 100 to its closed position to close the valve port 98 to its opened position to open the valve port 98. The o-ring 96 is received in the annular V-shape grooves R1 and R2 of the valve spool 94 and the framework 92 in such a manner that when the reed valve 100 is in its closing position, the two annular V-shape grooves R1 and R2 are substantially in registration with one another. Thus, the same advantage as that of the valve assembly 90A of Fig. 8A, i.e., a long operation life of the o-ring 96 can be obtained by the valve assembly 90B.

[0051] Figure 9 is a longitudinal cross-sectional view of a scroll type refrigerant compressor, a typical rotary type refrigerant compressor, to which the present invention is applied.

[0052] The scroll type refrigerant compressor of Fig. 9 includes a fixed scroll element 101 formed to be integral with a shell element forming an outer framework of the compressor, and front and rear housings 102 and 103 sealingly attached to opposite ends of the fixed scroll element 101. The fixed scroll element 101 is provided with a fixed side plate 101a and a fixed spiral member 101b integrally attached to the fixed side plate 101a. The front housing 102 supports therein a drive shaft 105 to be rotatable about an axis of rotation thereof via a radial bearing 104. The drive shaft 105 has an outer end connectable to an external drive source, and an inner end having a slide key member 106 arranged to be eccentric with the axis of rotation of the drive shaft 105 and projecting axially. The slide key member 106 holds thereon a drive bush 107 so that the drive bush 107 is permitted to radially slide with respect to the slide key member 106.

[0053] The scroll type refrigerant compressor further includes a movable scroll element 109, which is held on the drive bush 107 via a radial bearing 108. The movable scroll element 109 is provided with a movable side plate 109a, and a movable spiral member 109b integrally attached to an inner face of the movable side plate 109a. The movable scroll element 109 having the movable side plate 109a and the spiral member 109b is engaged with the fixed scroll element 101 having the fixed side plate 101a and the fixed spiral member 101b to define a plurality of compression chambers P therebetween.

[0054] The front housing 102 is further provided with a plurality of pins 111 fixed thereto. Similarly, the movable side plate 109a of the movable scroll element 109 is provided with a plurality of pins 112 fixed thereto. The pins 111 of the front housing 102 and the pins 112 of the movable scroll element 109 are engaged in a ring-like retainers 113, respective, which are slidably seated in a recess counter-bored in the inner face of the front housing 102, to prevent the movable scroll element 109 from self-rotating.

[0055] The fixed side plate 101a of the fixed scroll element 101 is centrally provided with a discharge passage 101c bored therein and having an outer open end closed by a reed type discharge valve 114 which is permitted to open until it comes into contact with a valve retainer 115.

[0056] A discharge chamber 106 is formed in both the fixed scroll element 101 and the rear housing 103 for receiving a compressed refrigerant discharged from the compression chambers P and the discharge passage 101c. The discharge chamber 116 communicates with an oil separating chamber 119 via a short passage 118 formed in the rear housing 103.

[0057] An oil storing chamber 117 is formed in both the fixed scroll element 101 and the rear housing 103 which is arranged to receive an oil separated from the compressed refrigerant within the above-mentioned oil separating chamber 119 via an oil passage 120 formed in a bottom portion of the oil separating chamber 119.

[0058] A valve assembly 50A is assembled in a portion of the fixed side plate 101a of the fixed scroll element 101 in a posture reverse to that of the valve assembly 50 of the reciprocating type refrigerant compressor of Fig. 1. The function of the valve assembly 50A is the same as that of the valve assembly 50. Thus, the valve assembly 50A is provided with a first valve chamber 55a in which a bellows element 56 is arranged to have one end fixed to the bottom of the chamber 55a and to be able to expand and contract within the first valve chamber 55a. The interior of the bellows element 56 communicates, via a pressure introducing passage 57, with one of the compression chambers P in which an intermediate pressure smaller than a final pressure of the compressed refrigerant prevails. An upstream side oil passage 61a extending from the oil storing chamber 117 is fluidly connected to a second valve chamber 55b. A downstream side oil passage 61b extends from the first valve chamber 55a to an opening formed in a portion of a slidably engaging portion of the fixed spiral portion 101b and the movable side plate 109a. Therefore, when the scroll type refrigerant compressor is driven to move the movable scroll element 109 with respect to the fixed scroll element 101, so that each of the compression chambers P is spirally displaced from an initial position to a final position while compressing the refrigerant, the compressed refrigerant is discharged from the compression chamber P to the discharge chamber 116 via the discharge passage 101c and the discharge valve 114. The compressed refrigerant further goes from the discharge chamber 116 into the oil separating chamber 119 via the short passage 118, so that the compressed refrigerant is spirally rotated along the cylindrical inner wall of the oil separating chamber 119 and around an oil-separating cylinder 121 fixed to an outer portion of the rear housing 103.

[0059] Thus, the compressed refrigerant is finally delivered from a delivery port formed in the oil-separating cylinder 121 toward the external refrigerating system. During the rotation of the compressed refrigerant around the oil-separating cylinder 121, an oil component suspended in the refrigerant is separated therefrom due to centrifugal force. Thus, the compressed refrigerant can be delivered into the external refrigerating system after the amount of oil contained in a unit weight of compressed refrigerant is sufficiently reduced to prevent heat exchanging units in the refrigerating system such as a condenser and an evaporator from being adversely affected by the oil component contained in the refrigerant from the viewpoint of thermal exchange.

[0060] During the operation of the scroll type refrigerant compressor, a pressure introduced into the interior of the bellows element 56 of the valve assembly 50A from the compression chamber P is very high and accordingly, the high pressure in the interior of the bellows element 56 expands the bellows element 56 against a combined force of a pressure prevailing in the first valve chamber 55a and the elastic restoring force of the bellows element 56 so as to keep the valve assembly 50A open. Therefore, the oil is supplied from the oil storing chamber 117 to the above-mentioned slidably engaging portion of the fixed spiral portion 101b and the movable side plate 109a which is a suction pressure region of the compressor to lubricate there.

[0061] It should be understood that the intermediate pressure introduced from the compression chamber P can be very stable due to a specific characteristic peculiar to the rotary type refrigerant compressor.

[0062] When the scroll type compressor is stopped, the pressure introduced from the compression chamber P and prevailing in the interior of the bellows element 56 is reduced to a low pressure substantially equal to the suction pressure of the compressor. Thus, the valve assembly 50A is quickly closed to fluidly disconnect the downstream side oil passage 61b from the upstream side oil passage 61a. Therefore, no oil is supplied from the oil storing chamber 117 to the slidably engaging portion of the movable and fixed scroll elements 109 and 101. Accordingly, when the scroll type refrigerant compressor is started, oil compression does not occur.

[0063] From the foregoing description of the several preferred embodiments of the present invention, it will be understood that according to the present invention, a refrigerant compressor is provided with an oil storing chamber having a sufficient volume for storing substantially the entire amount of the oil which can be circulated within the interior of the compressor and the oil suspended in the compressed refrigerant is separated from the refrigerant before the compressed refrigerant is delivered from the compressor to an external refrigerating system. Namely, the amount of oil contained in a unit weight of compressed refrigerant delivered from the compressor to the external refrigerating system is appreciably reduced and accordingly, the heat exchanging efficiency in the external refrigerating system can be remarkably increased.

[0064] Further, the circulation of the oil component within the refrigerant compressor is immediately started as soon as the compressing operation of the compressor is started, and therefore, lubrication in the interior of the compressor can be ensured even at the time of starting of the operation of the compressor. This fact means that, since the crank chamber of the compressor is not required to hold a specific amount of oil for the purpose of lubricating the interior in the crank chamber at the start of the compressing operation of the compressor, oil compression can be surely prevented when the compressing operation of the compressor is started.

[0065] Further, since the valve assembly incorporated in a refrigerant compressor employs an elastic restoring force of either a bellows element or a o-ring to control the opening and closing of a valve port located in a portion of an oil passage from an oil storing chamber to a lubricated portion of the compressor, the valve port can be surely and stably opened and closed by a movable valve element. Thus, an accurate control of the circulation of the oil within the compressor can be ensured. In addition, the valve assembly can be simple in its construction.

[0066] Finally, it should be understood that many and various changes and modifications will occur to a person skilled in the art without departing from the scope and spirit of the invention as claimed in the accompanying claims.

Claims

1. A positive-displacement-type refrigerant compressor including:

a suction system to receive a refrigerant at a suction pressure from an external refrigerating system,
a compressing mechanism having a compression chamber in which the refrigerant introduced from said suction system is compressed and discharged into a discharge chamber receiving the compressed refrigerant at a discharge pressure, and
an oil-separating and lubricating system for lubricating an interior of said positive-displacement-type refrigerant compressor by an oil separated from the refrigerant,
wherein said oil-separating and lubricating system comprises:
an oil-separating unit accommodated in a high pressure region communicating with said discharge chamber to cause a separation of an oil from the compressed refrigerant;
an oil-storing chamber accommodated in said high pressure region to store the oil separated by said oil-separating unit;
an oil-supply passage to supply the oil from said oil-storing chamber to said suction system;
a valve assembly disposed in a portion of said oil-supply passage for regulating an amount of flow of the oil from said oil-storing chamber to said suction system,
said valve assembly comprising:
a first valve chamber having a substantial volume therein;
a movable valve actuating element accommodated in said first valve chamber to be moved by an application of a pressure thereto against an elastic force, said movable valve actuating element defining outer and inner separate regions, one of which fluidly communicates with a downstream side of said oil-supply passage, and the other of which fluidly communicating with said compression chamber;
a second valve chamber arranged adjacent to said first valve chamber via a partition wall provided therebetween and fluidly communicating with an upstream side of said oil-supply passage;
a valve element extending from said movable valve actuating element and opening and closing a valve port bored in said partition wall to provide a fluid communication between said upstream and downstream of said oil-supply passage, said valve element moving in response to a movement of said movable valve actuating element and closing said valve port when the pressure introduced from said compression chamber and acting on said movable valve actuating element is overcome by the elastic restoring force acting on said movable valve actuating element; and
a restriction arranged in a portion of said oil-supply passage for applying a flow restricting effect to the oil flowing through said oil-supply passage.

2. A positive-displacement-type refrigerant compressor according to claim 1, wherein said movable valve actuating element comprises a bellows element having a fixed end fixed to a portion of said first valve chamber, a movable end connected to said valve element and expanding and contracting with respect to said fixed end, and an interior chamber formed as said inner region between said fixed and movable ends, said bellows element further having an exterior region therearound as said outer region of said first valve chamber.

3. A positive-displacement-type refrigerant compressor according to claim 2, wherein said interior chamber of said bellows element communicates with said compression chamber of said compressing mechanism, and said exterior region around said bellows element communicates with said downstream side of said oil-supply passage.

4. A positive-displacement-type refrigerant compressor according to claim 2, wherein said interior chamber of said bellows element communicates with said downstream side of said oil-supply passage and said exterior region around said bellows element communicates with said compression chamber of said compressing mechanism.

5. A positive-displacement-type refrigerant compressor according to claim 1, wherein said valve port bored in said partition wall is arranged to form a portion of said oil-supply passage and cooperates with said valve element to define a narrow passage portion functioning as said restriction.

6. A positive-displacement-type refrigerant compressor according to claim 1, wherein said oil-storing chamber is formed to have a volume suitable for storing substantially all of the oil component filled in said compressor and circulated through said suction system and said oil-separating and lubricating system of said compressor.

7. A positive-displacement-type refrigerant compressor according to claim 1, wherein said movable valve actuating element comprises:

a spool valve element disposed in said first valve chamber and having an outer face facing an inner wall of said first valve chamber via a small gap; and

an o-ring element deformably disposed in said small gap and fitted in a pair of annular recesses formed in said inner wall of said first valve chamber and said outer face of said spool valve element to movably support said spool valve element, said valve element being arranged to extend from said valve spool element and able to open and close said valve port bored in said partition wall in response to a movement of said valve spool element which can be moved by said pressure introduced from said compression chamber against said elastic force caused by a deformation of said o-ring element.

8. A positive-displacement-type refrigerant compressor according to claim 7, wherein said o-ring element received in said pair of annular recesses formed in said inner wall of said first valve chamber and said outer face of said spool valve element is preliminarily deformed to exhibit a predetermined amount of elastic force urging said valve element toward its closing position to close said valve port, said o-ring being further deformed when said valve element is moved to its opened position to open said valve port.

9. A positive-displacement-type refrigerant compressor according to claim 7, wherein said valve assembly further comprises an elastic element constantly applying a pressure to said valve element to thereby urge said valve element toward its closed position to close said valve port, said valve element being moved from its closed position to its open position by said pressure introduced from said compression chamber against a combination of said pressure of said elastic element and the elastic force of said o-ring.

10. A positive-displacement-type refrigerant compressor according to claim 1, wherein a pressure-introduction passage, for introducing said pressure from said compression chamber into a position acting on said valve element, is provided and has a flow restriction therein.

11. A positive-displacement-type refrigerant compressor according to claim 1, wherein, when said positive-displacement-type refrigerant compressor employs reciprocating pistons to compress the refrigerant, said pressure acting on said valve element can be maintained substantially at an average of the pressures prevailing in the compression chamber.

12. A positive-displacement-type refrigerant compressor according to claim 1, wherein, when said positive-displacement-type refrigerant compressor is a rotary type refrigerant compressor, said pressure acting on said valve element can be an intermediate value of the pressures prevailing in the compression chamber.

Fig. 1

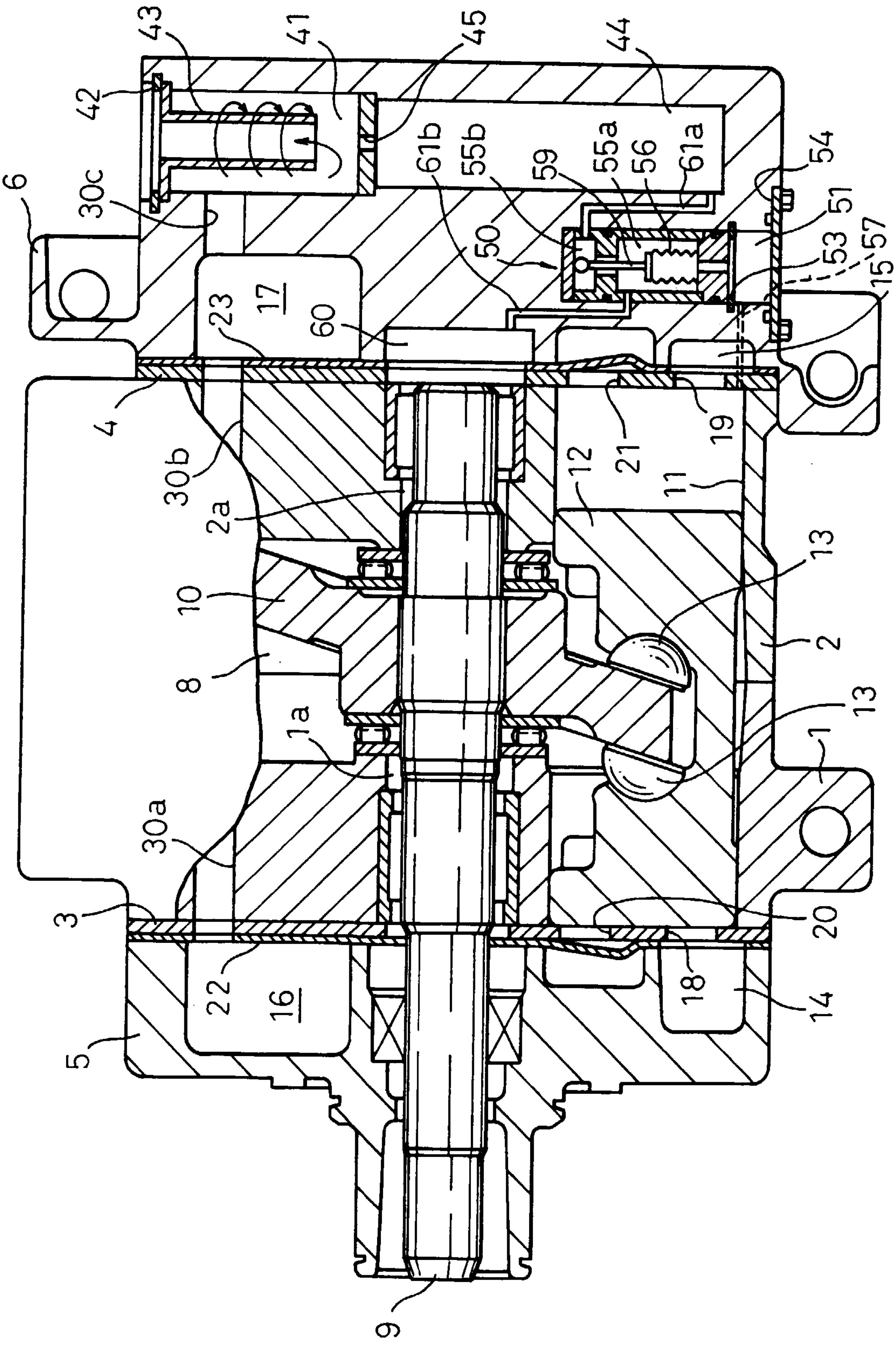
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Fig. 2

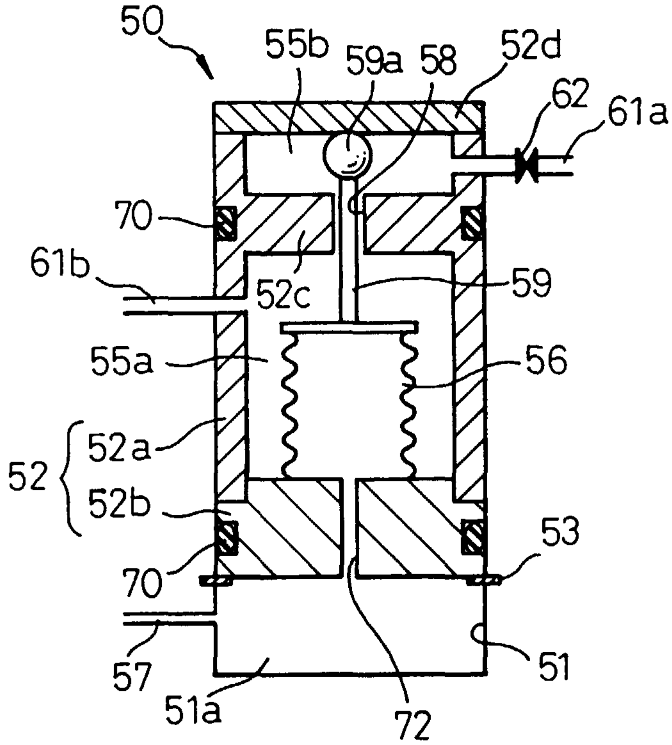
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Fig. 3

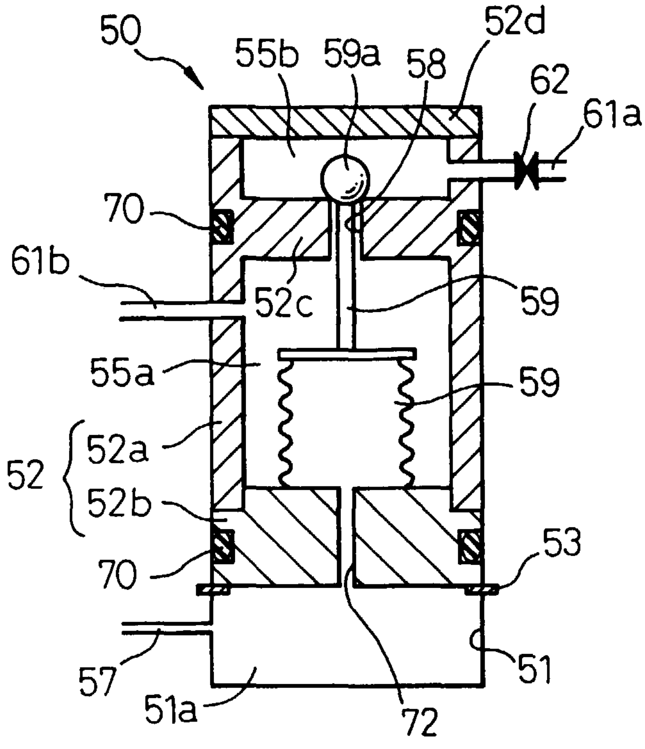
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Fig. 4

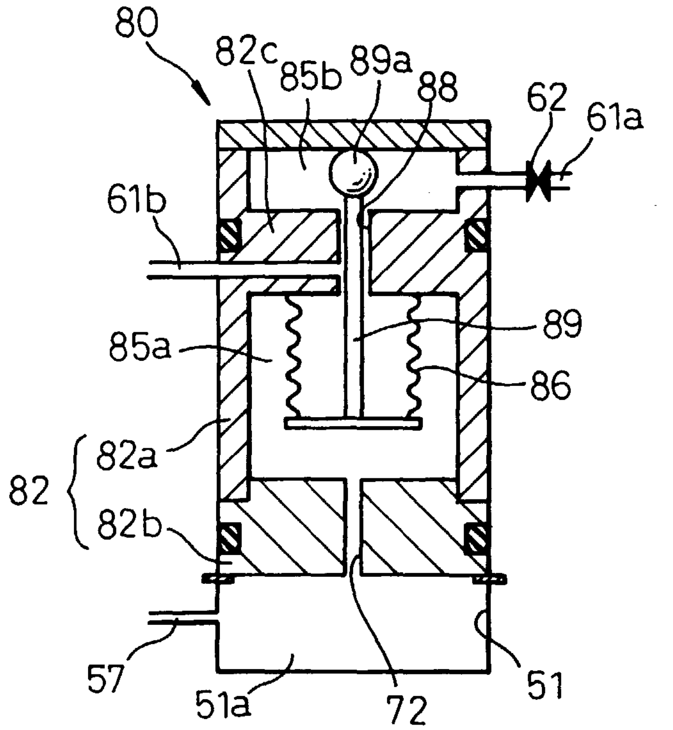
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Fig. 5

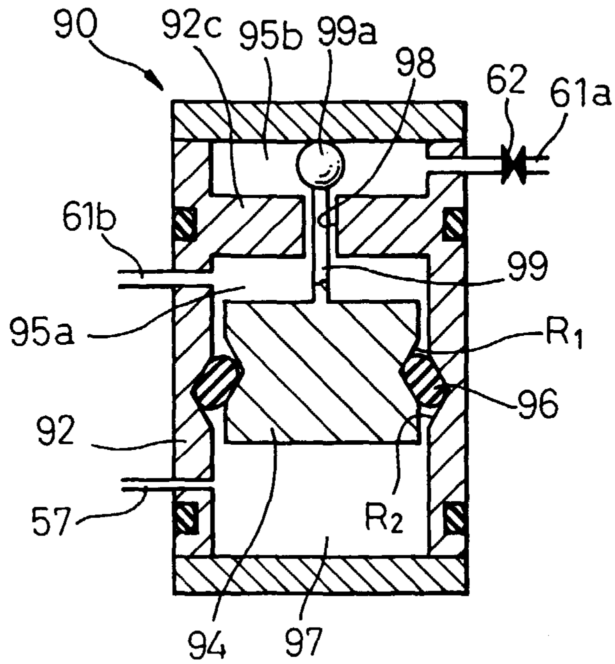
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Fig. 6

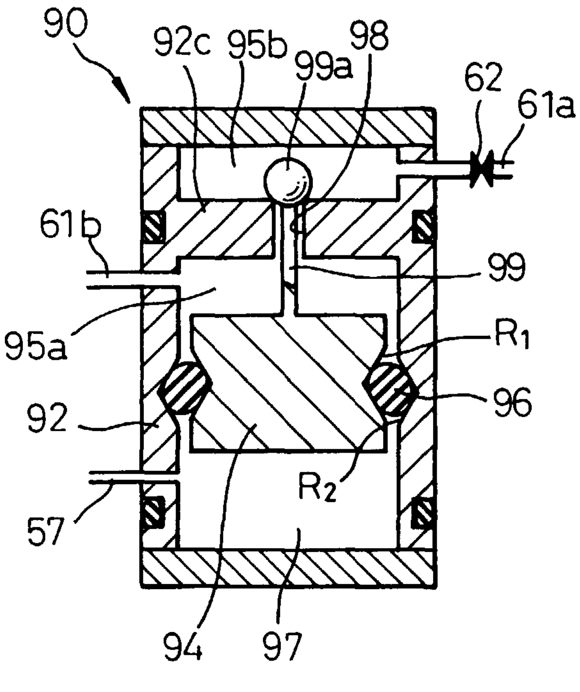


Fig.7A Fig.7B Fig.7C

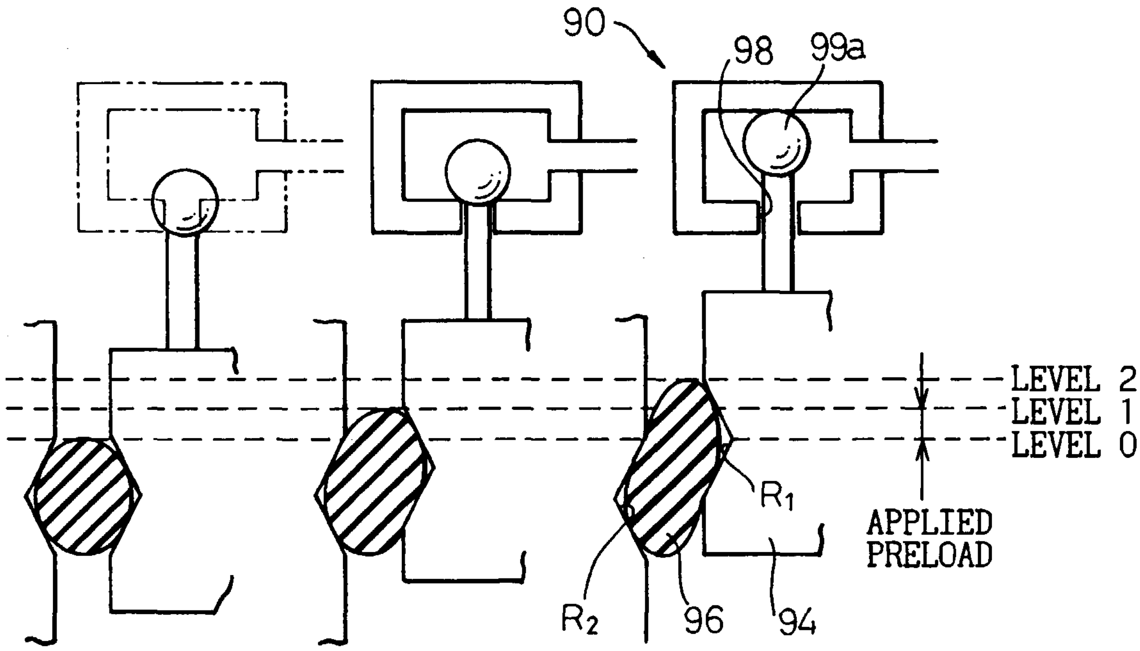


Fig. 8A Fig. 8B

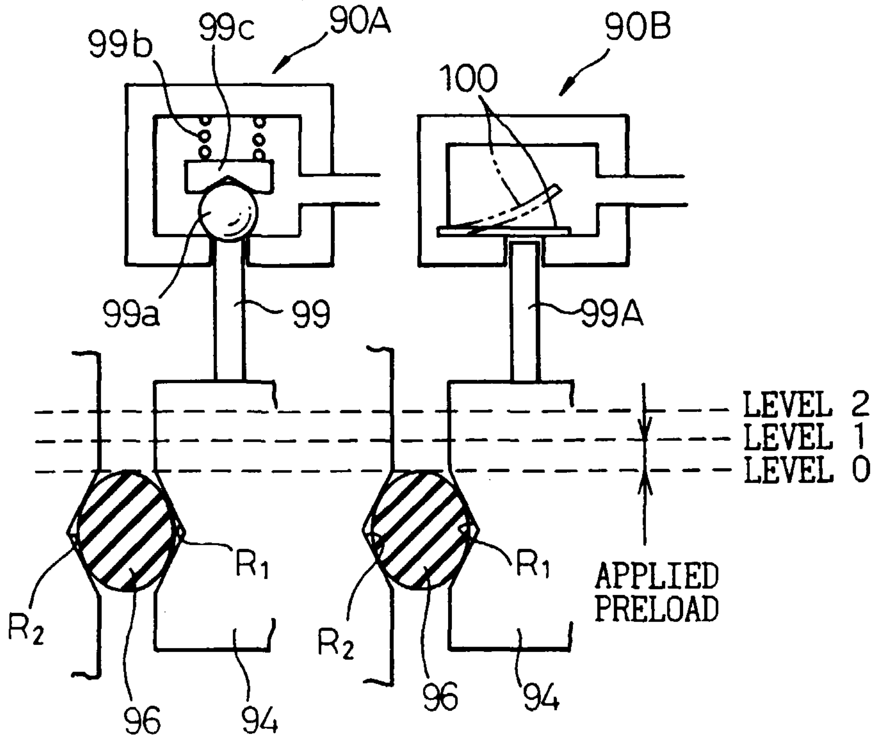
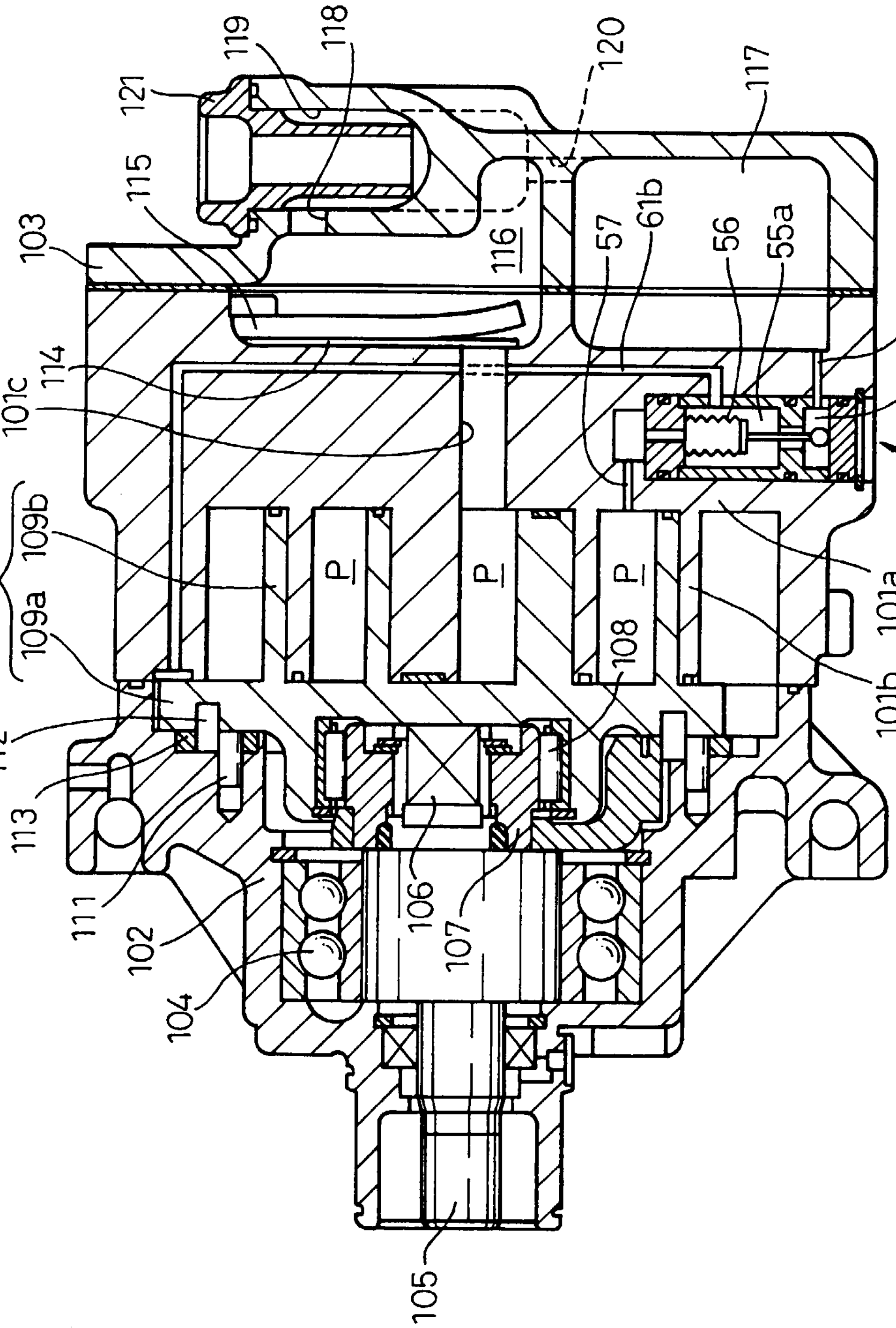


Fig.9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