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(71) Applicant: **Kabushiki Kaisha Toyota Jidoshokki**
Kariya-shi, Aichi-ken (JP)

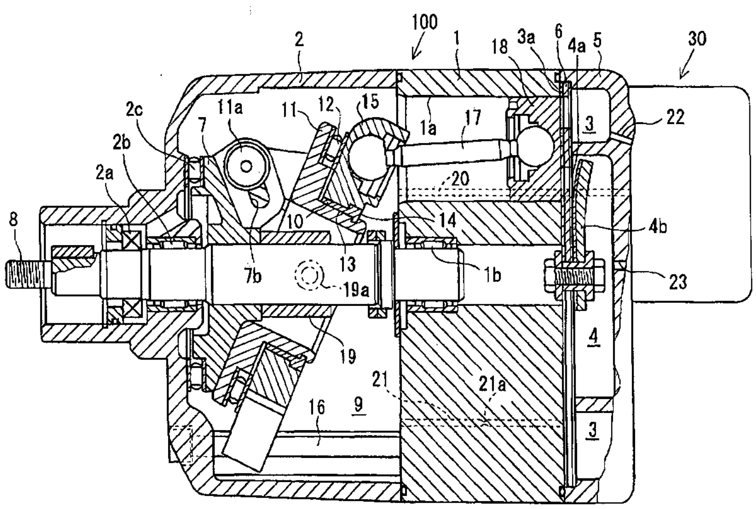
(72) Inventors:
- **Kawaguchi, Masahiro**
  Kariya-shi, Aichi-ken (JP)
- **Umemura, Satoshi**
  Kariya-shi, Aichi-ken (JP)
- **Koumura, Satoshi**
  Kariya-shi, Aichi-ken (JP)
- **Ota, Masaki**
  Kariya-shi, Aichi-ken (JP)
- **Tarutani, Tomoji**
  Kariya-shi, Aichi-ken (JP)

(74) Representative:
Leson, Thomas Johannes Alois, Dipl.-Ing.
Patentanwälte
Tiedtke-Bühling-Kinne & Partner,
Bavariaring 4
80336 München (DE)

(54) Variable capacity swash plate type compressor

(57) A variable displacement type compressor circulates a fluid in an air conditioning circuit. The compressor has a compression mechanism and a displacement control valve. The compression mechanism compresses the fluid. The displacement control valve controls discharge amount of the fluid of the compressor. In a first predetermined range of discharge pressure, suction pressure decreases at a first variation as the discharge pressure increases. In a second predetermined range of the discharge pressure that is higher than the first predetermined range, the suction pressure varies at a second variation as the discharge pressure increases. The second variation is constituted of at least one of a third variation that is smaller than the first variation and at which the suction pressure decreases as the discharge pressure increases, a fourth variation at which the suction pressure increases as the discharge pressure increases, and substantially zero.

FIG. 1



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Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates generally to a variable displacement type compressor adapted for use in an air conditioner, and more specifically to a displacement control system for the variable displacement type compressor which makes it possible to achieve the desired air conditioning performance by appropriately controlling the displacement of the compressor.

[0002] A variable displacement type compressor, for example, for use in an automotive air conditioner has incorporated therein a control valve for controlling discharge amount of a refrigerant. In the compressor equipped with such a control valve, operating performance of the air conditioner varies depending on the relationship between the discharge pressure and suction pressure of the refrigerant. FIG. 12 shows three different operating regions A, B and C of the compressor, indicated by shaded areas, in connection with the relationship between the discharge pressure Pd and suction pressure Ps of the refrigerant. The region A represents a region where the compressor is operating under a low cooling load and with low discharge pressure Pd. In such an operating state, a mist tends to be formed on the interior surface of vehicle windshield with an increase in the suction pressure Ps and hence the refrigerant pressure at the outlet of an evaporator connected in the air conditioning system, thus offering a problem of insufficient de-misting performance of the air conditioner. In the region B where the compressor is operating similarly under a low cooling load and with a low discharge pressure Pd, the evaporator tends to be frosted with a decrease in the suction pressure Ps. In the region C where the compressor is in operation under a high cooling load and with high discharge pressure, cooling performance of the air conditioner tends to be reduced with an increase in the suction pressure Ps. Thus, there has been a demand for a control system of an air conditioner which is designed in view of the above problems.

[0003] Various displacement control valves for an air conditioning system are disclosed in Japanese Unexamined Patent Publications No. 4-321779, No. 6-123279 and No. 7-119642, which are designed to achieve the desired air conditioning performance by appropriately controlling the displacement of a variable displacement type compressor. A compressor using such displacement control valve can prevent the aforementioned problems by achieving Pd-Ps characteristic as represented by a curve in FIG. 12.

[0004] According to the Pd-Ps characteristic curve of FIG. 12, however, the suction pressure is decreased excessively in the control region of high cooling loads and the compressor is operated continuously, with the result that the engine for driving the compressor is applied with an excessive load and the coolant in a radiator of the engine is heated accordingly.

SUMMARY OF THE INVENTION

[0005] The present invention relates to a variable displacement type compressor, an air conditioning system equipped with such a compressor and a method for controlling the displacement of such a compressor which will not impose an excessive load on an engine while the compressor is running under a high load.

[0006] According to the present invention, a variable displacement type compressor circulates a fluid in an air conditioning circuit. The fluid is drawn into a suction region before compression. The pressure in the suction region is defined as suction pressure. The fluid is discharged to the discharge region after compression. The pressure in the discharge region is defined as discharge pressure. The suction region is connected to the discharge region. The compressor has a compression mechanism and a displacement control valve. The compression mechanism compresses the fluid. The displacement control valve controls discharge amount of the fluid of the compressor. In a first predetermined range of the discharge pressure the suction pressure decreases at a first variation as the discharge pressure increases. In a second predetermined range of the discharge pressure that is higher than the first predetermined range the suction pressure varies at a second variation as the discharge pressure increases. The second variation is constituted of at least one of a third variation that is smaller than the first variation and at which the suction pressure decreases as the discharge pressure increases, a fourth variation at which the suction pressure increases as the discharge pressure increases, and substantially zero.

[0007] The present invention also provides a method for controlling displacement in a variable displacement type compressor that circulates a fluid in an air conditioning circuit. The fluid is drawn into a suction region before compression. The pressure in the suction region is defined as suction pressure. The fluid is discharged to the discharge region after compression. The pressure in the discharge region is defined as discharge pressure. The suction region is connected to the discharge region. The method comprises the steps of decreasing the suction pressure at a first variation as the discharge pressure increases in a first predetermined range of the discharge pressure, setting a third variation that is smaller than the first variation and at which the suction pressure decrease as the discharge pressure increases in a second predetermined range of the discharge pressure that is higher than the first predetermined range, setting a fourth variation at which the suction pressure increases as the discharge pressure increases in the second predetermined range, setting a second variation by using at least one of the third variation, the fourth variation, and substantially zero in the second predetermined range, and varying the suction pressure at the second variation as the discharge pressure increases in the second predetermined range.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The features of the present invention that are believed to be novel are set forth with particularity in the appended claims. The invention together with objects and advantages thereof, may best be understood by reference to the following description of the presently preferred embodiments together with the accompanying drawings in which:

Fig. 1 is a longitudinal sectional view illustrating a variable displacement swash plate type compressor 100 according to a preferred embodiment of the present invention;

FIG. 2 is an enlarged longitudinal sectional view illustrating a displacement control valve 30, which is shown in FIG. 1, under a low-load control range R3 according to the preferred embodiment of the present invention;

FIG. 3 is an enlarged perspective view illustrating a valve box 60, a valve body 40 and a partial discharge pressure correction rod 41 in FIG. 2 according to the preferred embodiment of the present invention;

FIG. 4 is an enlarged longitudinal sectional view illustrating a displacement control valve 30, which is shown in FIG. 1, under an intermediate-load control range R1 according to the preferred embodiment of the present invention;

FIG. 5 is an enlarged longitudinal sectional view illustrating a displacement control valve 30, which is shown in FIG. 1, under a high-load control range R2 according to the preferred embodiment of the present invention;

FIG. 6 is a graph illustrating a Pd-Ps characteristic curve when the displacement control valve 30 according to the preferred embodiment of the present invention is used;

FIG. 7 is a schematic view illustrating various forces acting in the displacement control valve 30 during compressor operation in the low-load control range R3 according to the preferred embodiment of the present invention;

FIG. 8 is a schematic view illustrating various forces acting in the displacement control valve 30 during compressor operation in the intermediate-load control range R1 according to the preferred embodiment of the present invention;

FIG. 9 is a schematic view illustrating various forces acting in the displacement control valve 30 during compressor operation in the high-load control range R2 according to the preferred embodiment of the present invention;

FIG. 10 is a longitudinal sectional view illustrating a displacement control valve 130 according to another preferred embodiment of the present invention;

FIG. 11 is a cross sectional view illustrating a spring 80, spring washers 81 and 82, a through hole 82a, a valve body 40 and a partial discharge pressure correction rod according to yet another preferred embodiment of the present invention; and

FIG. 12 is a graph illustrating a Pd-Ps characteristic curve when a displacement control valve according to a prior art is used.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0009] The following will describe a preferred embodiment of a variable displacement type compressor according to the present invention while having reference to the accompanying drawings. It is noted the following description will deal with a variable displacement swash plate type compressor adapted for use in an automotive air conditioning system.

[0010] Referring firstly to FIG. 1, the variable displacement swash plate type compressor 100 (referred to merely as "compressor" hereinafter) includes a cylinder block 1 having formed therein a plurality of cylinder bores 1a arranged around the central axis of the cylinder block 1 and each receiving therein a reciprocally movable piston 18. A front housing 2 is sealingly fastened to the front end of the cylinder block 1, and a rear housing 5 is similarly fastened to the rear end of the cylinder block 1 with a valve plate assembly 6 interposed therebetween. The cylinder block 1 and the front housing 2 cooperate to define a crank chamber 9 as a crank chamber pressure region in which a wobble plate 15 and its associated parts are disposed as will be described in detail in later part hereof.

[0011] The rear housing 5 has formed therein a suction chamber 3 as a suction region or a suction pressure region into which refrigerant before compression is drawn and a discharge chamber 4 as a discharge region or a discharge pressure region into which refrigerant compressed in the respective cylinder bores 1a is discharged. The valve plate assembly 6 is formed therethrough with a suction port for providing communication between the suction chamber 3 and each cylinder bore 1a through a suction valve 3a and also with a discharge port for communication between the discharge chamber 4 and each cylinder bore 1a through a discharge valve 4a. A retainer 4b is fixed in the discharge chamber 4 so as to limit the maximum opening of the discharge valve 4a. On the rear side of the rear housing 5 is provided a displacement control valve 30 serving as the displacement control means of the present invention which will be described in detail in later part hereof.

[0012] A first supply passage 20 extends through the cylinder block 1 and the rear housing 5 for communication between the crank chamber 9 and the displacement control valve 30. A bleed passage 21 having therein an orifice 21a is formed in the cylinder block 1 for communication between the crank chamber 9 and the suction chamber 3. Furthermore, the rear housing 5 has formed therein a pressure sensing passage 22 and a second supply passage 23 for communication of the suction chamber 3 and the discharge chamber 4 with the displacement control valve 30, respectively, as will be described more in detail with reference to FIG. 2.

[0013] As shown in FIG. 1, a drive shaft 8 is disposed in the crank chamber 9 and rotatably supported in the cylinder block 1 and the front housing 2 by bearings 1b and 2b arranged in the cylinder block 1 and the front housing 2, respectively. The drive shaft 8 is connected at the front end thereof to a vehicle engine by way of a suitable clutching means such as electromagnetic clutch (not shown). A shaft seal 2a is provided between the drive shaft 8 and the front housing 2. It is noted that the compressor 100 may dispense with the clutch so that the drive shaft 8 is driven constantly by means of a belt and pulley arrangement.

[0014] A rotor 7 is fixedly mounted on the drive shaft 8 for rotation therewith in the crank chamber 9 with a thrust bearing 2c disposed between the rotor 7 and the inner wall of the front housing 2, and a sleeve 19 is axially slidably mounted on the drive shaft 8 adjacent to the rotor 7. The rotor 7 is formed with an elongated through-hole 7b through which a pin 11a of a swash plate 11 is inserted slidably in the elongated through-hole 7b. The swash plate 11 is rotatable with the drive shaft 8 and pivotally supported by a pair of trunnion pins 19a projecting from opposite sides of the sleeve 19 so that, as the drive shaft 8 is rotated, the swash plate 11 makes a nutational motion about the drive shaft 8 at an inclination angle. A wobble plate 15 is fitted to the swash plate 11 by way of a thrust bearing 12, a plane bearing 10, a race 13 and a thrust washer 14, and a guide rod 16 extends in the crank chamber 9 to prohibit rotation of the wobble plate 15. Each of the pistons 18 received in the cylinder bores 1 a is connected to the wobble plate 15 by a rod 17. In operation, the wobble plate 15 makes a wobbling movement in response to the nutational motion of the swash plate 11 and the pistons 18 connected to the wobble plate 15 are caused to move reciprocally in their associated cylinder bores 1 a. Refrigerant is drawn from the suction chamber 3 into the cylinder bore 1a during the suction stroke of the piston 18 and then compressed in and then discharged out of the cylinder bore 1a during the discharge stroke of the piston 18, thus compressed refrigerant being discharged into the discharge chamber 4.

[0015] Displacement of the compressor 100 depends on the length of stroke of the piston 18 and such stroke length varies with the inclination angle of the swash plate 11. To be more specific, the stroke length of the piston 18 and hence the displacement is increased with an increase of the angle at which the swash plate 11 is inclined with respect to a plane perpendicular to the axis of the drive shaft 8, and vice versa. This inclination angle of the swash plate 11 during compressor operation is determined by the pressure differential between the pressure in the cylinder bores 1a and in the crank chamber 9, and this pressure differential is adjusted by the displacement control valve 30.

[0016] The following will describe the structure of the displacement control valve 30 while having reference to FIGs. 2 and 3.

[0017] Referring to firstly FIG. 2, the displacement control valve 30 includes a main valve portion 33, a cylindrical housing 31 fixed at one end thereof to one end of the main valve portion 33, and a cap 38 fixed to the other end of the main valve portion 33. An adjusting portion 32 is screwed into the other end of the cylindrical housing 31 by way of an O-ring, and an insert 37 is disposed in the cap 38.

[0018] The main valve portion 33, the cylindrical housing 31 and the adjusting portion 32 cooperate to define a suction pressure chamber 51 as a suction region which is in communication with the suction chamber 5 via the aforementioned pressure sensing passage 22 in the rear housing 5 and radial passages 51a formed in the cylindrical housing 31. Thus, suction pressure Ps prevails in the suction pressure chamber 51 of the displacement control valve 30. Within the suction pressure chamber 51 is disposed a bellows 36 having one end thereof fixed to the adjusting portion 32 and the other end thereof engaged with a rod 35 which is slidably disposed in an axial bore formed in the main valve portion 33. The bellows 36 has therein a spring 36a urging the bellows 36 in the direction indicated by arrow F_1 and the bellows interior is maintained under vacuum. F_1 represents the sum of the elastic force of the bellows 36 and the urging force of the spring 36a both acting in the same arrow direction. The bellows 36, which serves as the suction pressure Ps sensitive means of the invention, has an effective pressure sensing area S1 to which suction pressure Ps acts in the direction opposite to the arrow direction F_1. It is noted that any suitable means such as diaphragm may be used in place of the bellows 36 as the suction pressure Ps sensitive means of the invention.

[0019] The rod 35 is slidable in the axial bore in the main valve portion 33 by contraction or expansion of the bellows 36. The main valve portion 33 has formed therein at an intermediate position thereof an axial bore 20b into which the distal end of the rod 35 extends and first radial supply ports 20a extending radially from the axial bore 20b. The first supply ports 20a are in communication with the aforementioned first supply passage 20 formed through the cylinder block 1 and the rear housing 5 for communication with the crank chamber 9. The axial bore 20b is formed with a cross sectional area S2.

[0020] The main valve portion 33 and the insert 37 define therebetween a discharge pressure chamber 52 as a discharge region which is in communication with the discharge chamber 4 through the second supply passage 23 formed in the rear housing 5 and second radial supply ports 23a which are formed in the main valve portion 33. The first supply passage 20, the first supply port 20a, the second supply passage 23 and the second supply port 23a constitute communication routes of the variable displacement type compressor according to the present invention.

[0021] The insert 37 and the cap 38 have defined therebetween a crank pressure chamber 53 as a crank chamber pressure region which is in communication with the crank chamber 9 of the compressor 100 by way of a communication passage 33a formed in the main valve portion 33.

[0022] The insert 37 is formed at the axial center thereof with an axial bore through which a discharge pressure correction rod 41, which serves as the discharge pressure sensitive means of the invention, is slidably inserted. This rod 41 has a flange portion 41 a disposed in the discharge pressure chamber 52 and a stem portion 41b passing through the insert 37 and extending into the crank pressure chamber 53. A spring 42 having a spring constant k_2 is provided in the crank pressure chamber 53 for urging the correction rod 41 toward the discharge pressure chamber 52 as indicated by arrow 70 with force F_2. The stem portion 41 b of the correction rod 41 has a cross sectional area S3.

[0023] As shown in FIGs. 2 and 3, a valve box 60 serving as the rod supplementing member of the invention is disposed within the discharge pressure chamber 52, and a valve body 40 in the form of a spherical ball serving as the valve means of the invention and part of the correction rod 41 including its flange portion 41 a and part of the stem portion 41 b adjacent to the flange portion 41a are incorporated within the valve box 60. A spring 63 with a spring constant k_3 is disposed between the flange portion 41a and the inner end of the valve box 60. Part of the valve body 40 which protrudes out of the valve box 60 through its first opening 61 is contactable with the rod 35. The discharge pressure correction rod 41 is movable axially through the opposite second opening 62 of the valve box 60. The discharge pressure correction rod 41, the spring 42 and the valve box 60 constitute the urging means of the present invention. Reference numeral 39 designates a valve seat for the valve body 40.

[0024] It is noted that the cross sectional areas of S1, S2 and S3 of the bellows 36, the axial bore 20b and the stem portion 41b of the correction rod 41, respectively, are provided such that S1>S3>S2.

[0025] The compressor 100 having incorporated therein such displacement control valve 30 is disposed in a refrigeration circuit together with a condenser, expansion valve, evaporator, etc. (not shown). When the drive shaft 8 is driven to rotate by vehicle engine, the swash plate 11 is rotated at an inclined angle by the rotor 7 that is fixed on and hence rotatable with the drive shaft 8. The wobble plate 15 fitted to the swash plate 11 makes a wobbling movement at the inclined angle of the swash plate 11, which causes the pistons 18 to move reciprocally in their associated cylinder bores 1a for a stroke length corresponding to the inclined angle of the wobble plate 15. In so doing, refrigerant flowing from the evaporator to the suction chamber 3 is drawn into the cylinder bore 1a then in suction stroke. Refrigerant introduced in the cylinder bore 1a is compressed by the piston 18 and then discharged into the discharge chamber 4.

[0026] As is apparent from the foregoing description, the displacement control valve 30 is provided as an internal control mechanism of the compressor 100 wherein the valve body 40 of the displacement control valve 30 is operable by way of the bellows 36 as the suction pressure sensitive means and the discharge pressure correction rod 41 as the discharge pressure sensitive means, respectively.

[0027] The displacement control valve 30 thus constructed is configured such that a Pd-Ps characteristic curve as indicated by a solid line in FIG. 6 is achieved, as compared with a curve of a dotted line achievable by prior art.

[0028] Referring now specifically to FIG. 6 showing two Pd-Ps characteristic curves, wherein the solid line curve shows Pd-Ps characteristic achievable by use of the displacement control valve 30 of the illustrated embodiment, while the dotted line curve represents similar characteristic of the prior art control valves. In the diagram of Fig. 6, symbols T1 and T2 depict inflection points of Pd-Ps characteristic curve of the displacement control valve 30, so that the curve may be divided into three line sections L1, L2 and L3 by such inflection points T1 and T2.

[0029] The displacement control valve 30 is configured to operate as follows. In the low-load control region R3 (or the third mode in the invention) corresponding to the line section L3 where the compressor 100 is operating under a low discharge pressure Pd and hence with a low displacement, suction pressure Ps increases with an increase in discharge pressure Pd. In the intermediate-load control range R1 (or the first mode in the invention) corresponding to the line section L1 between the inflection points T1 and T2 where discharge pressure Pd is in a middle range, the suction pressure Ps decreases with an increase of discharge pressure Pd. In the high-load control range R2 corresponding to the line section L2 (or the second mode in the invention) where the compressor 100 is operating under a high discharge pressure Pd and hence with a high displacement, suction pressure Ps is maintained substantially at a constant level irrespective of a change of discharge pressure Pd. In the control range R2, suction pressure Ps is prevented from being dropped.

[0030] As shown in FIG. 6, the Pd-Ps characteristic describes a curve so that it avoids interference with any of the shaded region A where a mist tends to be produced, the region B where evaporator frosting tends to occur and the region C where cooling performance tends to be decreased. In other words, the compressor 100 operating according the Pd-Ps characteristic curve can forestall these three problems.

[0031] As appreciated from FIG. 6, suction pressure Ps in the intermediate-load control range R1 between the inflection points T1 and T2 is generally raised or set higher than that of the characteristic curve attainable by the prior art control valves as indicated by a dotted line, without interfering with the operating region C. Furthermore, suction pressure Ps in the high-load control range R2 of the Pd-Ps characteristic curve is maintained substantially while avoiding interference with the operating region C. As is apparent from comparison with the dotted line, maintenance of a substantially constant suction pressure Ps in the high-load control range R2 is accomplished by providing the inflection point T2 between the line sections L1 and L2 so as to differentiate the inclinations of the line sections L1 and L2.

[0032] According to the Pd-Ps characteristic curve of the displacement control valve 30 wherein suction pressure Ps is set higher than heretofore in the intermediate-load control range R1, fuel consumption can be improved. Additionally, suppressing a decrease of suction pressure Ps in the high-load control range R2 helps not only to improve the fuel consumption but also to prevent temperature rise of coolant in a vehicle radiator.

[0033] The following will describe the operation of the displacement control valve 30 in the control ranges R3, R1 and R2 with reference to FIGs. 2, 4, 5 and 6.

[0034] FIG. 2 shows a state of the displacement control valve 30 when the compressor 100 is operating under a low load in the control range R3. The discharge pressure correction rod 41 is urged in the direction of the arrow 70 by the spring 42, and the valve body 40 is pushed by the correction rod 41 accordingly to be seated on the valve seat 39, so that the axial bore 20b which is in communication with the crank chamber 9 through the first supply passage 20 in the cylinder block 1 is shut off from the discharge pressure chamber 52. That is, the discharge chamber 4 and the crank chamber 9 are shut off from each other. In this state of FIG. 2, the spring 63 has one end thereof free from contact with its adjacent inner surface of the valve box 60 and hence provides no urging action. Because the crank chamber 9 and the suction chamber 3 are in communication with each other by way of the bleed passage 21 having therein the orifice 21 a, part of the refrigerant in the crank chamber 9 flows into the suction chamber 3. Since flowing of refrigerant under high pressure from the discharge chamber 4 into the crank chamber 9 is shut off, crank chamber pressure Pc is reduced and the back pressure acting on the pistons 18 is reduced, accordingly. Therefore, the inclination angle of the wobble plate 15 is increased thereby to increase the stroke length of the pistons 18, with the result that the displacement is increased. In this state of the displacement control valve 30, the valve body 40 is not lifted off from the valve seat 39 unless suction pressure Ps in the suction pressure chamber 51 is substantially reduced relatively to the force F_1. Therefore, suction pressure Ps is increased with a build-up of discharge pressure Pd. At this state, the crank chamber pressure Pc and the suction pressure Ps are maintained substantially to be equal to each other.

[0035] From the schematic diagram of FIG. 7 showing various forces acting in the displacement control valve 30 during compressor operation in the low-load control range R3, the equilibrium state of such forces can be expressed by equation (1), and transforming this equation (1), the relationship between suction pressure Ps and discharge pressure Pd can be expressed by equation (2), as follows.

$$F1 - S1 \cdot Ps + S2 \cdot Ps - S2 \cdot Pd + S3 \cdot Pd - S3 \cdot Ps - F2 = 0 \tag{1}$$

$$Ps = - \{(S2 - S3) / (S1 - S2 + S3)\} \cdot Pd + (F1 - F2) / (S1 - S2 + S3) \tag{2}$$

[0036] Expressing the equation (2) in a coordinate system with discharge pressure Pd and suction pressure Ps represented by abscissa and ordinate, respectively, as shown in FIG. 6, the inclination of the line is determined by -(S2 - S3) / (S1 - S2 + S3). Since the cross-sectional areas of S1, S2 and S3 are such that S1>S3>S2, the inclination of the line, or the manner in which suction pressure Ps varies with discharge pressure in the Pd-Ps characteristic line, is positive. That is, the displacement control valve 30 provides Pd-Ps characteristic as shown by the line section L3 of FIG. 6 in the low-load control range R3.

[0037] Referring to FIG. 4 showing a state of the displacement control valve 30 when the compressor 100 is operating under an intermediate load in the control range R1, the discharge pressure correction rod 41 is moved in the direction of an arrow 72 with an increase of the discharge pressure Pd while overcoming the urging force of the spring 42. Thus, the pressing force to keep the valve body 40 in closed position by the correction rod 41 is cancelled. In this state of the discharge pressure correction rod 41, the spring 63 is merely moved in the direction of the arrow 72 with the correction rod 41, exerting no urging force. The valve body 40 is moved off the valve seat 39 and, therefore, the first supply port 20a and the second supply port 23a become in communication with each other, thereby allowing refrigerant under a high pressure in the discharge chamber 4 to flow into the crank chamber 9 through the second supply passage 23, the second supply port 23a, the first supply port 20a and the first supply passage 20. As a result, crank chamber pressure Pc is increased and the back pressure acting on the pistons 18 is increased accordingly, so that the inclination angle of the wobble plate 15 is decreased. Thus, the stroke length of the pistons 18 is shortened, causing the displacement to be reduced. Since the suction pressure Ps in the suction pressure chamber 51 acts against F1, the force to open the valve body 40 is decreased with an increase of the suction pressure Ps.

[0038] From the schematic diagram of FIG. 8 showing various forces acting in the displacement control valve 30 while the compressor is operating in the intermediate-load control range R1, the equilibrium state of such forces can be expressed by equation (3), and transforming this equation (3), the relationship between suction pressure Ps and discharge pressure Pd can be expressed by equation (4), as follows.

$$F1 - Si \cdot Ps + S2 \cdot Ps - S2 \cdot Pd = 0 \tag{3}$$

$$Ps = - (S2 / (S1\text{-}S2)] \cdot Pd + F1 / (S1\text{-}S2) \tag{4}$$

[0039] Expressing the equation (4) in a coordinate system with the discharge pressure Pd and the suction pressure Ps represented by abscissa and ordinate, respectively, the inclination of the line is determined by -S2/(S1-S2). Since the cross-sectional area S1 is greater than S2, or S1 > S2, the inclination of the Pd-Ps characteristic line in the control range R1 is negative. That is, the displacement control valve 30 provides Pd-Ps control characteristic as shown by the line section L1 of FIG. 6 in the intermediate-load control range R1. The variation of suction pressure Ps with respect to discharge pressure Pd in the control range R1 is referred to as the first variation in the invention.

[0040] Now referring to FIG. 5 showing a state of the displacement control valve 30 when the compressor 100 is operating under a high load in the control range R2, the discharge pressure correction rod 41 is moved further in the direction of the arrow 72 with a buildup of the discharge pressure Pd while overcoming the urging force of the spring 42. With the correction rod 41 thus moved, the spring 63 begins to be compressed and to act against the force F2. After the spring 63 has been fully compressed, the valve box 60 and the valve body 40 are moved together with the discharge pressure correction rod 41 in the direction of the arrow 72 which causes the valve body 40 to open. That is, in the high-load control range R2, the valve body 40 is moved in its opening direction by cooperative action of the correction rod 41, the valve box 60 and the spring 63.

[0041] From the schematic diagram of FIG. 9 showing various forces acting in the displacement control valve 30 during compressor operation in the high-load control range R2, the equilibrium state of such forces is expressed by equation (5), and transforming this equation (5), the relationship between suction pressure Ps and discharge pressure Pd is expressed by equation (6), as follows.

$$F1 - S1 \cdot Ps + S2 \cdot Ps - S2 \cdot Pd - S3 \cdot Ps + k_3 \cdot x_3 - k_2 \cdot x_2 + S3 \cdot Pd - F2 = 0 \tag{5}$$

$$\begin{aligned} Ps = & - \{(S2-S3) / (S1-S2+S3)\} \cdot Pd - (k_2 \cdot x_2 - k_3 \cdot x_3) / (S1-S2+S3) \\ & + (F1-F2) / (S1-S2+S3) \end{aligned} \tag{6}$$

[0042] In the equation (6), the urging forces of the springs 42 and 63 are expressed by $k_2 \cdot x_2$ and $k_3 \cdot x_3$, respectively, wherein x_2 and x_3 represent the distances by which the respective springs 42 and 63 are compressed.

[0043] In the illustrated embodiment, the displacement control valve 30 operates in the high-load control range R2 such that Pd-Ps characteristic is represented by the line section L2 which is substantially flat as shown in FIG. 6. The variation of suction pressure Ps with respect to discharge pressure Pd in the control range R2 is referred to as the second variation in the invention. It is noted that, since the values x_2 and x_3 are dependent on discharge pressure Pd, the urging forces k_2x_2 and k_3x_3 of the springs 42 and 63, respectively, vary with discharge pressure Pd. Therefore, the inclination of the line section L2 depends on the values of the first and second terms of the right side of the equation (6).

[0044] As is now apparent from the foregoing, fuel consumption can be improved by elevating the suction pressure Ps in the intermediate-load control range R1 and also engine is not overloaded by suppressing a decrease of the suction pressure Ps in the high-load control range R2. In this control range R2, an excessive temperature rise of coolant of a vehicle engine can be prevented successfully. Thus, the proof stress of the compressor 100 can be ensured. As is apparent from FIG. 6, problems such as mist formation on the windshield surface and evaporator frosting which tends to occur in the low-load control range R3 can be forestalled.

[0045] Additionally, the displacement control valve 30 makes it possible to rationally control displacement of the compressor 100 in each of the control ranges R1, R2 and R3.

[0046] As is understood by those skilled in the art, the present invention is not limited to the above illustrated specific embodiment, but it can be practiced in various forms and changes, as exemplified below.

[0047] While in the above embodiment controlling is performed such that suction pressure Ps is maintained substantially constant irrespective of an increase in discharge pressure Pd in the high-load control range R2, controlling of suction pressure Ps in this range may be changed as required. For example, setting may be made such that change of suction pressure Ps with respect to a rise of discharge pressure Pd occurs in any combination of manners of changes which include decreasing of suction pressure Ps at a third variation which is smaller than the first variation in the intermediate-load control range R1, increasing of suction pressure Ps at a fourth variation and maintaining suction pressure Ps substantially constant.

[0048] Referring to FIG. 10 showing a modification of the present invention, a modified displacement control valve 130 is provided, wherein like reference numerals or symbols designate like elements or parts of the displacement control valve 30 of the preferred embodiment.

[0049] The cylindrical housing 31 is formed with third supply ports 23b communicating with the second supply passages 23 in the main valve body 33 and a discharge pressure chamber 152 as a discharge region where discharge pressure Pd prevails due to the communication of the above third supply port 23b and the second supply passage 23. In this embodiment, the first supply passage 20, the first supply port 20a, the second supply passage 23 and the second supply port 23a and the third supply port 23b constitute the communication routes of the variable displacement type compressor according to the present invention. A discharge pressure correction rod 141 is disposed within the discharge pressure chamber 152. The stem portion 141b of this correction rod 141 has a cross-sectional area S4. In the high-load control region R1, the discharge pressure correction rod 141 acts on the bellows 36 in the direction of an arrow 170, or rightward as seen in FIG. 10, against the urging force of a spring 142 disposed in the discharge pressure chamber 152 and having a spring constant k_4. These discharge pressure correction rod 141 and the spring 142 are referred to as the urging means of the invention. In operation in the high-load control range R2, the discharge pressure correction rod 141 and the spring 142 cooperate to urge the valve body 40 in the direction that causes the valve to open. In the control ranges R1 and R3, the displacement control valve 130 operates in the same manner as the counterpart 30 of the preferred embodiment.

[0050] Equilibrium state of forces acting in the displacement control valve 130 in the control range R2 is expressed by equations (7) and (8) below, wherein k_1 represents the spring constant of the spring 36a and x_1 represents the distances by which the bellows 36 is contracted.

$$Ps = -\{S1/(S1+S2)\}\, Pd + (k_1 \cdot x_1) / (S1+S2) + F1/(S1+S2) \qquad (7)$$

$$F1 + k_1 \cdot x_1 = (Pd - Ps) \cdot S4 - k_4 \cdot x_4 \qquad (8)$$

[0051] In the equation (8), the contraction distance x_4 and hence the urging force $k_4 \cdot x_4$ of the spring 142 is dependent on discharge pressure Pd, the inclination of the line section L2 for the high-load control range R2 depends on the values of the first and second terms of the right side of the equation (7).

[0052] Referring to FIG. 11 showing a further modification of the present invention, this modification differs from the preferred embodiment in the structure of valve box as the rod supplementing member of the invention. The rod supplementing member of FIG. 11 includes a spring 80 and spring washers 81 and 82. The discharge pressure correction rod 41 is disposed passing through a through-hole 82a formed in the spring washer 82. This rod supplementing member can perform the same function as the counterpart comprising the valve box 60 and the spring 63 of the preferred embodiment. Additionally, the spring 80 and the spring washer 82 may be substituted by a single member including a modified spring.

[0053] The present examples and preferred embodiments are to be considered as illustrative and not restrictive, and the invention is not to be limited to the details given herein but may be modified within the scope of the appended claims.

Claims

1. A variable displacement type compressor that circulates a fluid in an air conditioning circuit, the fluid being drawn into a suction region before compression, the pressure in the suction region being defined as suction pressure, the fluid being discharged to the discharge region after compression, the pressure in the discharge region being defined as discharge pressure, the suction region being connected to the discharge region, the compressor comprising:

    a compression mechanism for compressing the fluid; and
    a displacement control valve for controlling discharge amount of the fluid of the compressor, in a first predetermined range of the discharge pressure the suction pressure decreasing at a first variation as the discharge pressure increases, in a second predetermined range of the discharge pressure that is higher than the first predetermined range the suction pressure varying at a second variation as the discharge pressure increases, the second variation being constituted of at least one of a third variation that is smaller than the first variation and at which the suction pressure decreases as the discharge pressure increases, a fourth variation at which the suction pressure increases as the discharge pressure increases, and substantially zero.

2. The variable displacement type compressor according to claim 1, wherein the suction pressure increases or is maintained to a predetermined value as the discharge pressure increases in the second predetermined range.

3. The variable displacement type compressor according to claim 1, wherein the suction pressure increases as the discharge pressure increases in a third predetermined range of the discharge pressure that is lower than the first predetermined range.

4. The variable displacement type compressor according to claim 3, wherein the discharge amount is controlled by introducing the compressed fluid from the discharge region to a crank chamber pressure region, the displacement control valve further comprising:

    a communication route communicating the discharge region and the crank chamber pressure region;
    a valve body for opening and closing the communication route by sensing the suction pressure and the discharge pressure; and
    an urging means for enabling to urge the valve body so as to open or close the communication route, the urging means urging the valve body so as to open the communication route in the second predetermined range.

5. The variable displacement type compressor according to claim 4 wherein the urging means urges the valve body so as to close the communication route in the third predetermined range.

6. The variable displacement type compressor according to claim 5, the urging means further comprising:

    a rod for contacting the valve body in the third predetermined range;
    a rod supplementing member for urging the valve body so as to open the communication route in the second predetermined range; and
    a spring for applying elastic urging force to the rod and the rod supplementing member, the rod and the rod supplementing member being operated based on a balance between the discharge pressure of the fluid and the elastic urging force of the spring.

7. The variable displacement type compressor according to claim 3, wherein the suction pressure and the discharge pressure have a first inflectional point that connects the third predetermined range to the second predetermined range.

8. The variable displacement type compressor according to claim 1, wherein the suction pressure and the discharge pressure have a second inflectional point that connects the first predetermined range to the second predetermined range.

9. An air conditioner comprising:

an air conditioning circuit including a fluid;
a condenser in the air conditioning circuit for condensing the fluid;
an expansion valve in the air conditioning circuit for expanding the condensed fluid;
an evaporator in the air conditioning circuit for evaporating the expanded fluid to exchange heat between the fluid and air in a room; and
a variable displacement type compressor in the air conditioning circuit for compressing the evaporated fluid, the fluid being drawn into a suction region before compression, the pressure in the suction region being defined as suction pressure, the fluid being discharged to the discharge region after compression, the pressure in the discharge region being defined as discharge pressure, the suction region being connected to the discharge region, the compressor comprising;

a compression mechanism for compressing the fluid; and
a displacement control valve for controlling discharge amount of the fluid of the compressor, in a first predetermined range of the discharge pressure the suction pressure decreasing at a first variation as the discharge pressure increases, in a second predetermined range of the discharge pressure that is higher than the first predetermined range the suction pressure varying at a second variation as the discharge pressure increases, the second variation being constituted of at least one of a third variation that is smaller than the first variation and at which the suction pressure decreases as the discharge pressure increases, a fourth variation at which the suction pressure increases as the discharge pressure increases, and substantially zero.

10. A method for controlling displacement in a variable displacement type compressor that circulates a fluid in an air conditioning circuit, the fluid being drawn into a suction region before compression, the pressure in the suction region being defined as suction pressure, the fluid being discharged to the discharge region after compression, the pressure in the discharge region being defined as discharge pressure, the suction region being connected to the discharge region, the method comprising the steps of:

decreasing the suction pressure at a first variation as the discharge pressure increases in a first predetermined range of the discharge pressure;
setting a third variation that is smaller than the first variation and at which the suction pressure decrease as the discharge pressure increases in a second predetermined range of the discharge pressure that is higher than the first predetermined range;
setting a fourth variation at which the suction pressure increases as the discharge pressure increases in the second predetermined range;
setting a second variation by using at least one of the third variation, the fourth variation, and substantially zero in the second predetermined range; and
varying the suction pressure at the second variation as the discharge pressure increases in the second predetermined range.

11. The method for controlling displacement in the variable displacement type compressor according to claim 10, wherein the second variation setting step comprises increasing the suction pressure or maintaining to a predetermined value as the discharge pressure increases.

12. The method for controlling displacement in the variable displacement type compressor according to claim 11, comprising the additional step of increasing the suction pressure as the discharge pressure increases in a third predetermined range of the discharge pressure that is lower than the first predetermined range.

13. The method for controlling displacement in the variable displacement type compressor according to claim 12, comprising the additional step of providing the suction pressure and the discharge pressure with a first inflectional point that connects the third predetermined range to the second predetermined range.

14. The method for controlling displacement in the variable displacement type compressor according to claim 10, comprising the additional step of providing the suction pressure and the discharge pressure with a second inflectional point that connects the first predetermined range to the second predetermined range.

FIG. 1

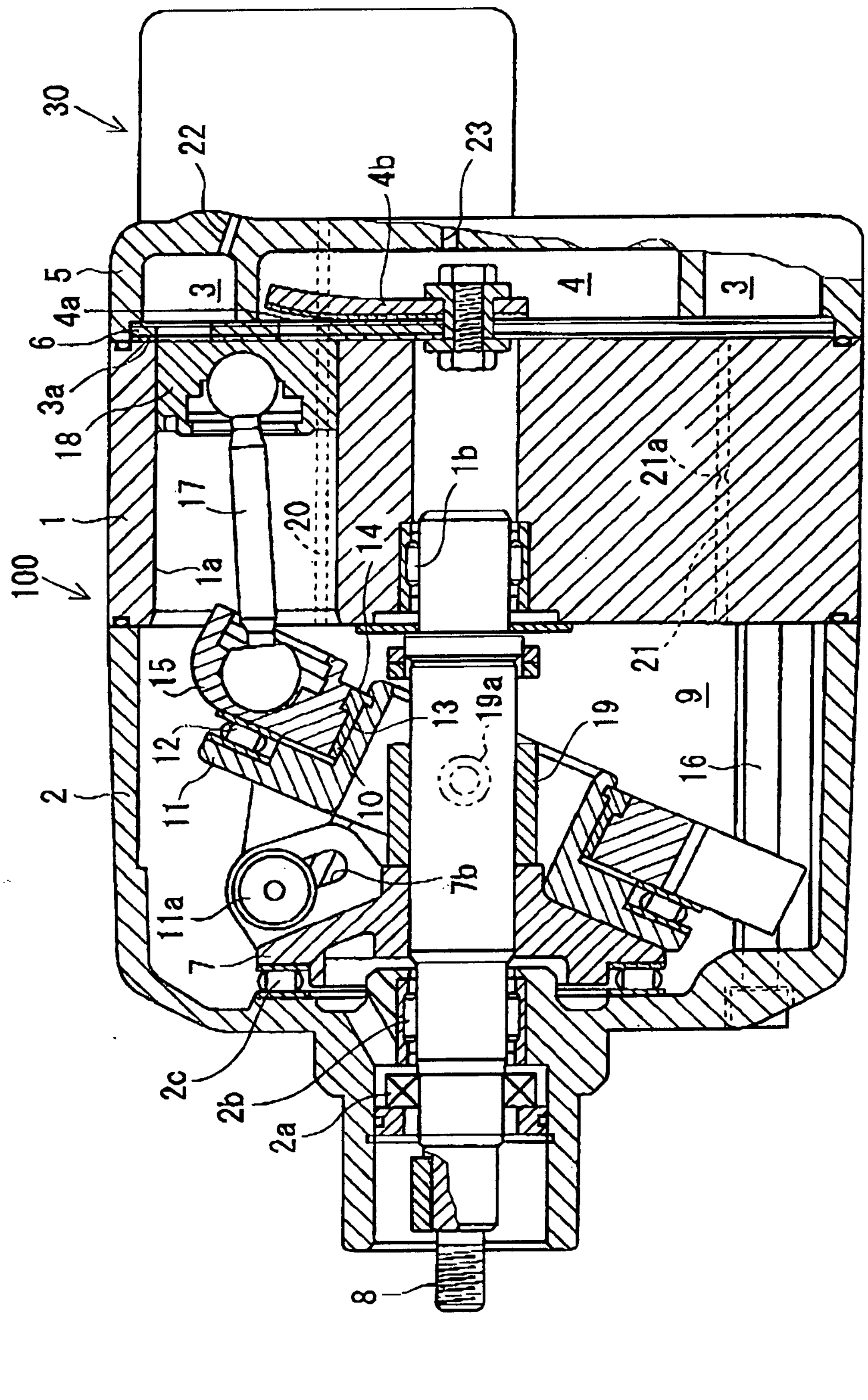
30
22
23
4b
5
3
4a
4
3
6
3a
18
1b
17
21a
1
20
14
1a
100
21
15
19a
13
9
12
19
11
10
16
2
11a
7b
7
2c
2b
2a
8

FIG. 2

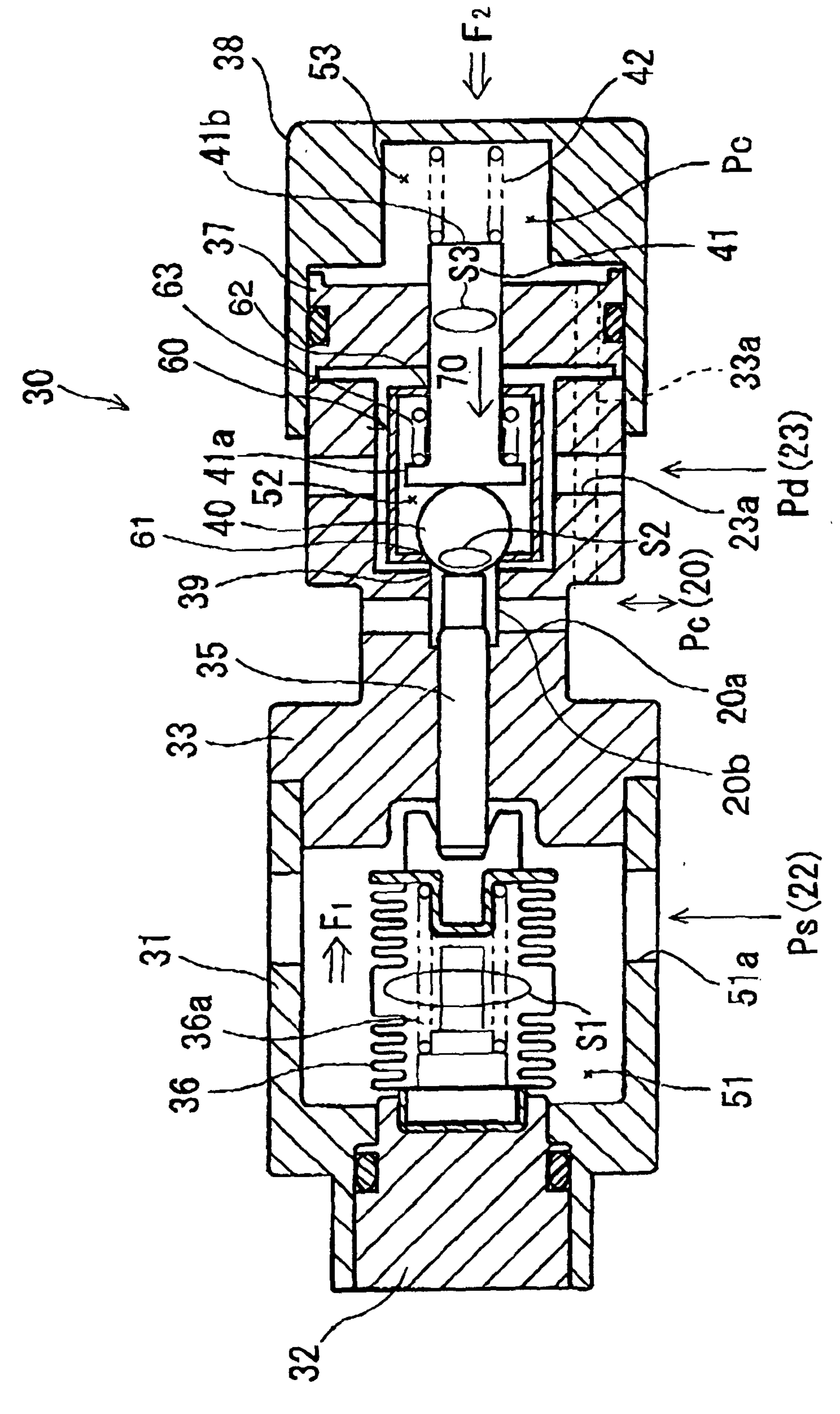
30
38
53
F2
42
41b
Pc
37
41
S3
63
62
60
70
33a
41a
52
40
61
S2
Pd (23)
23a
39
Pc (20)
35
20a
33
20b
Ps (22)
31
F1
36a
S1
51a
36
51
32

FIG. 3

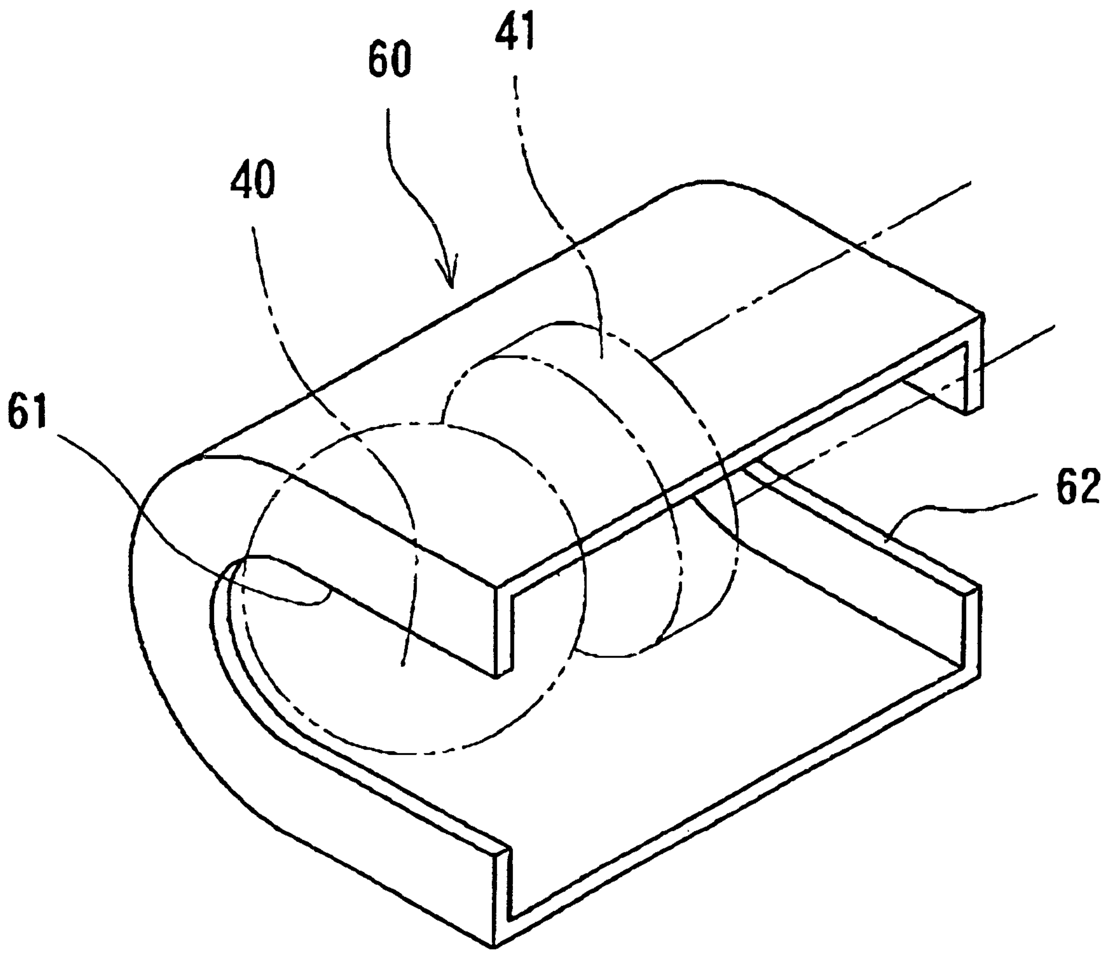

FIG. 4

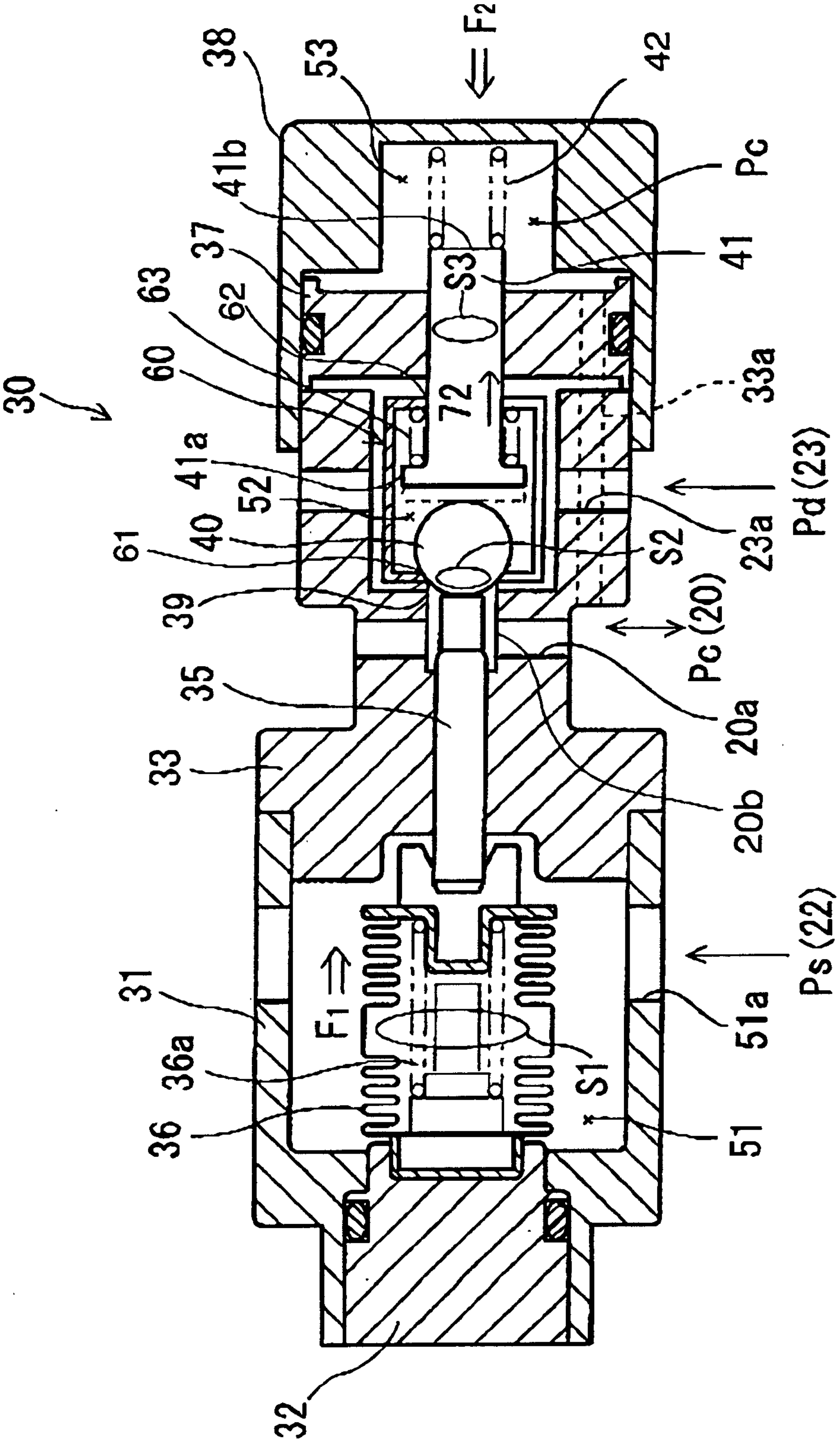
30
38
53
F_2
42
41b
37
63
62
60
72
41a
52
40
61
39
35
33
31
36a
36
32
S3
Pc
41
33a
Pd (23)
23a
S2
Pc (20)
20a
20b
Ps (22)
51a
51
S1
F_1

FIG. 5

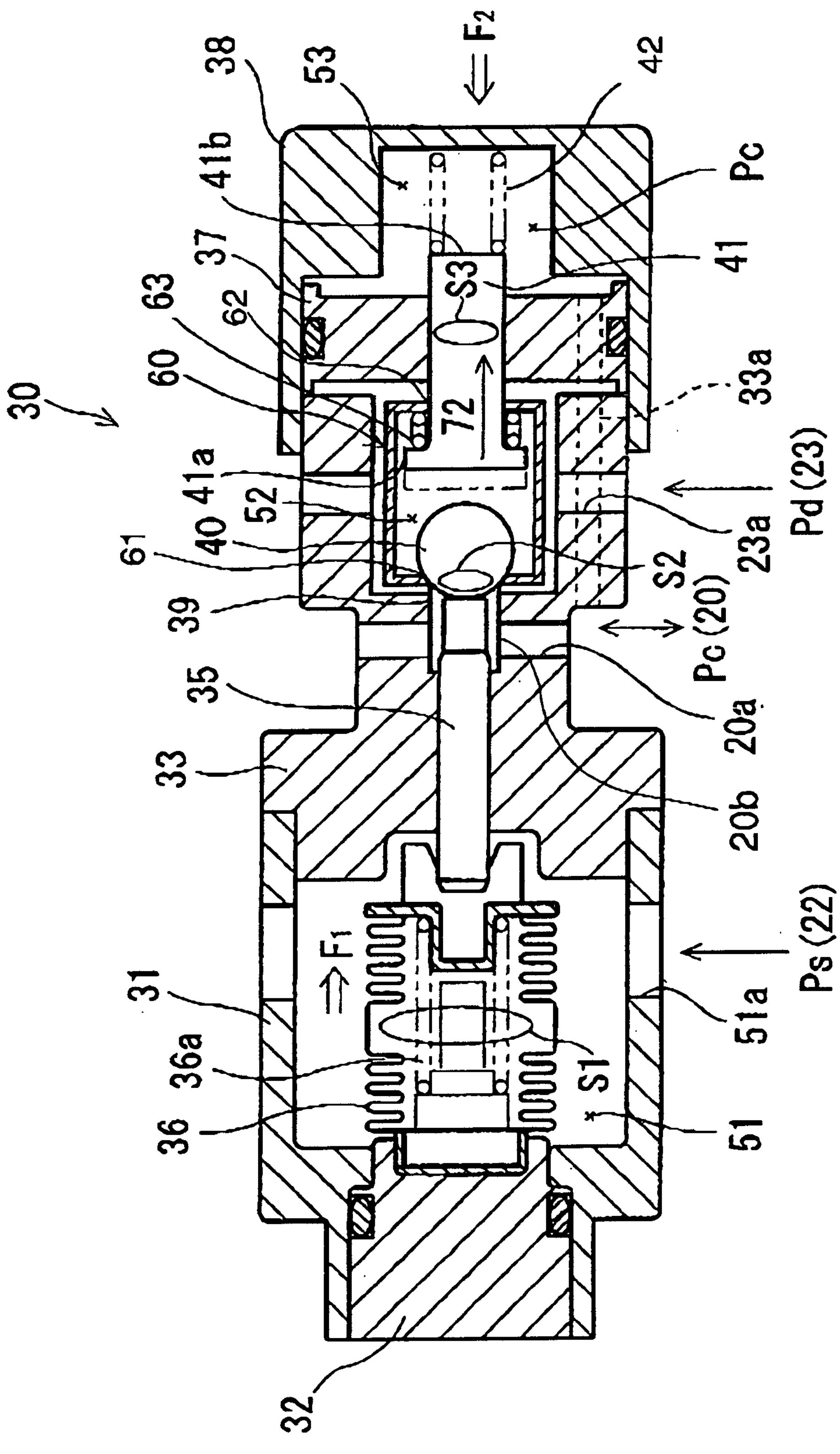
30
38
53
F2
42
41b
Pc
37
41
63
62
S3
33a
60
72
41a
Pd (23)
52
23a
40
61
S2
39
Pc (20)
35
20a
33
20b
31
F1
Ps (22)
36a
S1
51a
36
51
32

FIG. 6

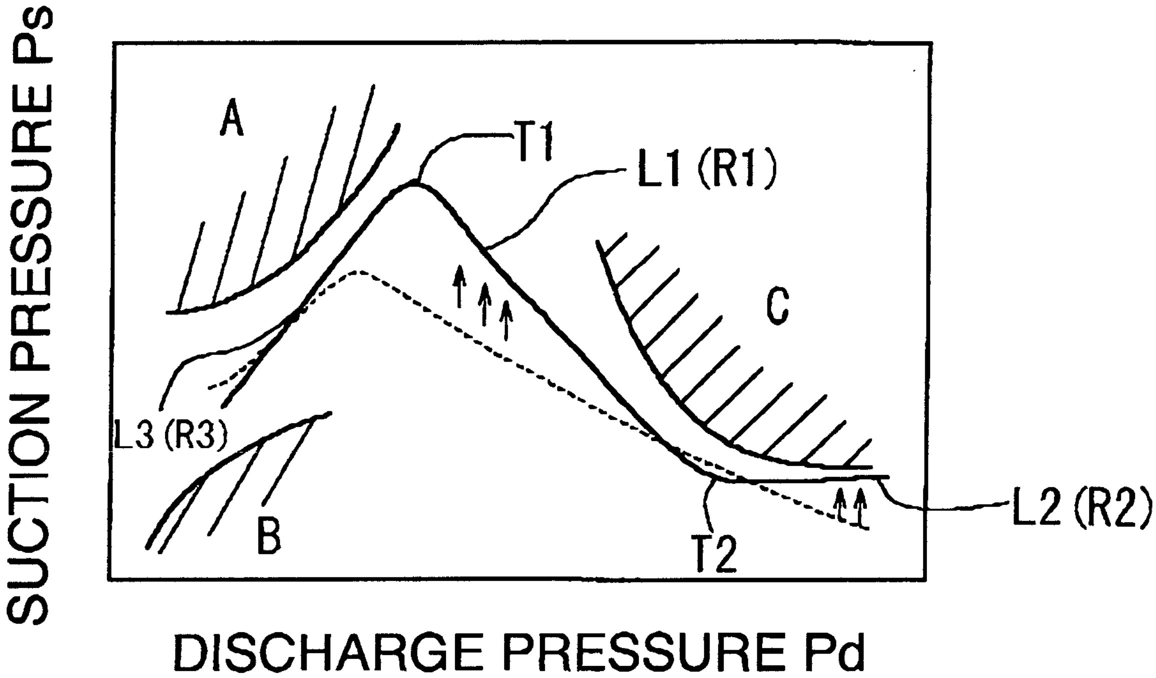
SUCTION PRESSURE Ps
A
T1
L1 (R1)
C
L3 (R3)
B
T2
L2 (R2)
DISCHARGE PRESSURE Pd

FIG. 7

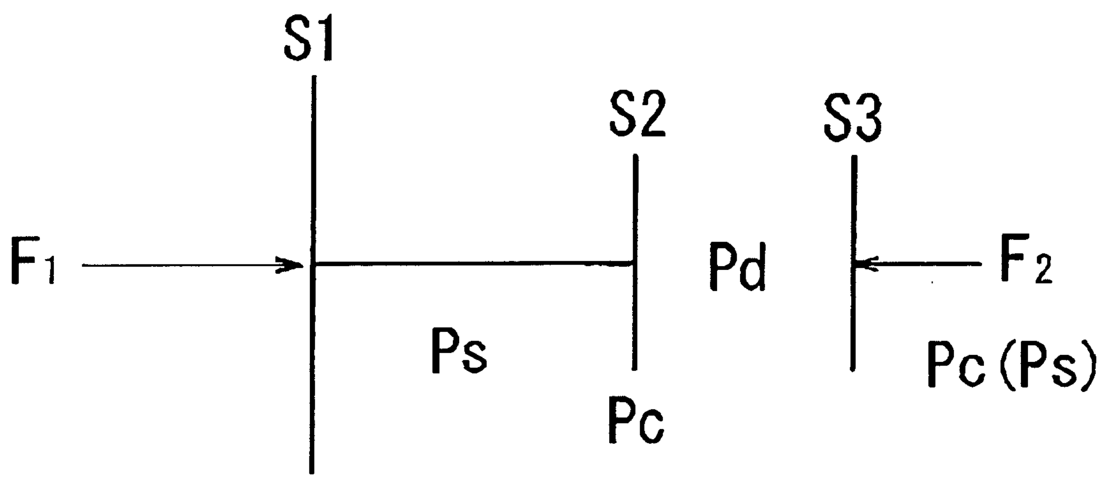
S1
S2
S3
F1
Pd
F2
Ps
Pc (Ps)
Pc

FIG. 8

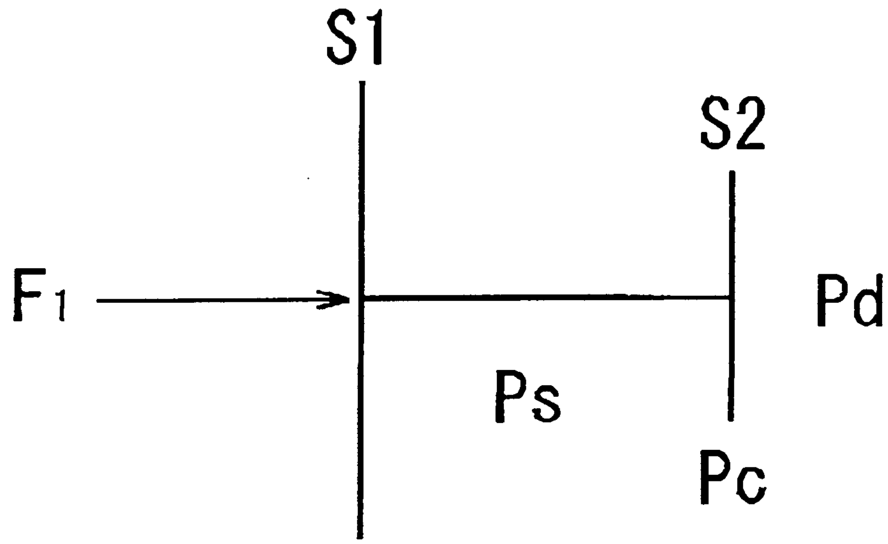

FIG. 9

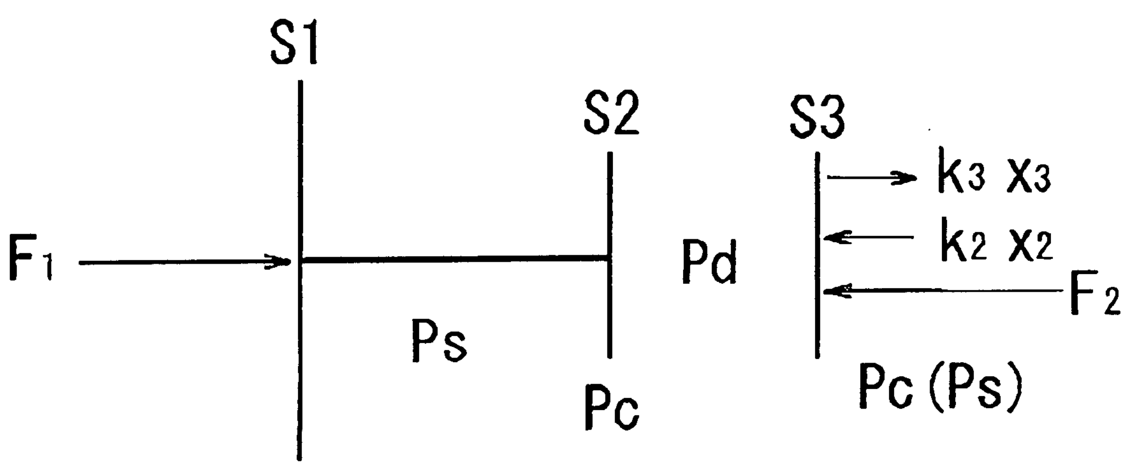

FIG. 10

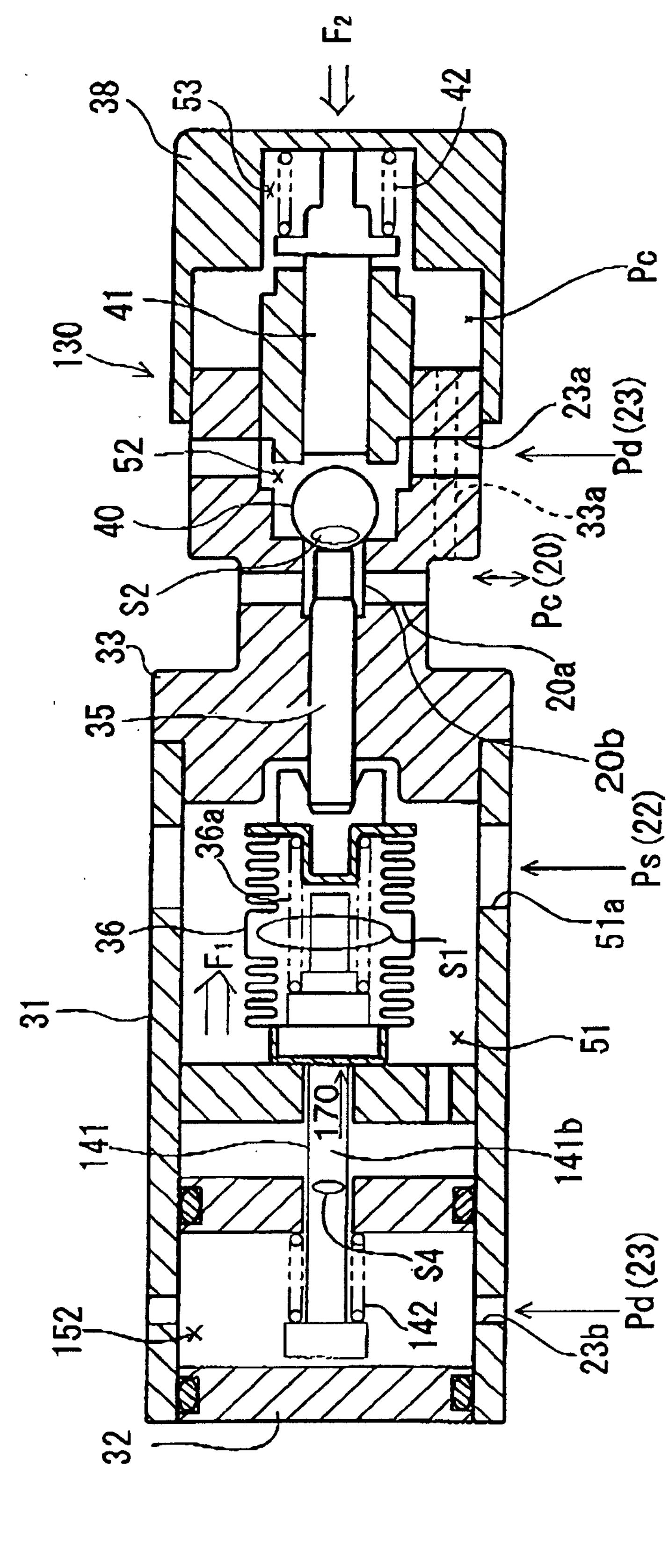
F2
38
53
42
Pc
41
130
23a
Pd (23)
52
40
33a
S2
Pc (20)
33
20a
35
20b
Ps (22)
36a
36
F1
S1
51a
31
51
170
141
141b
S4
152
142
Pd (23)
23b
32

FIG. 11

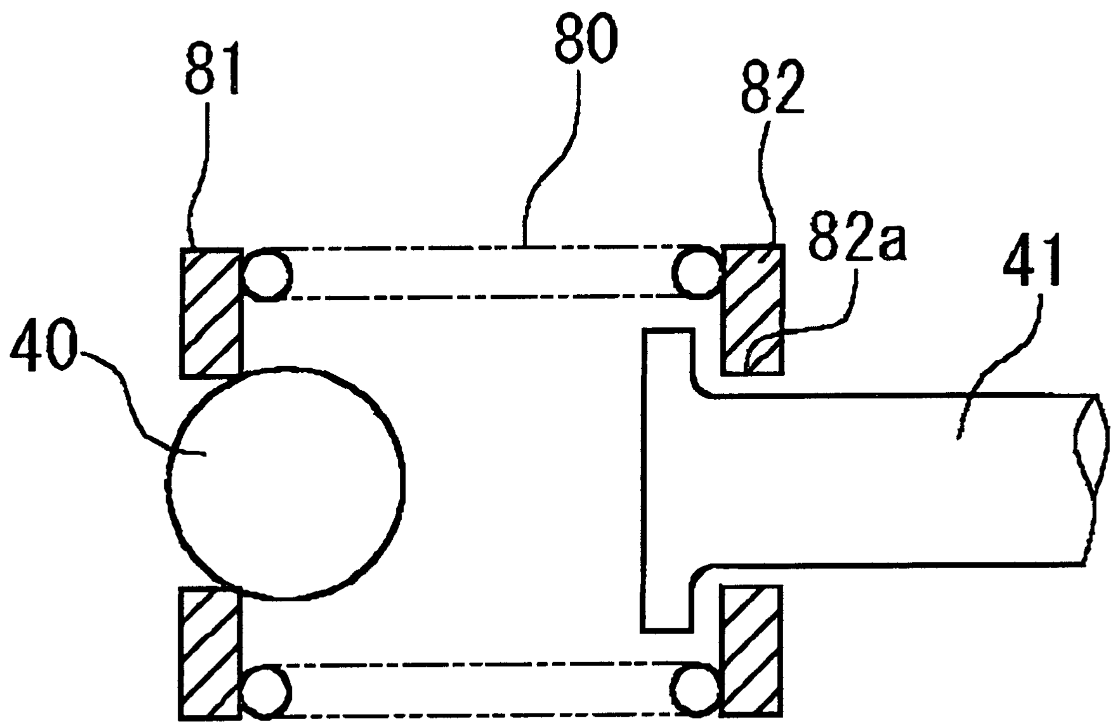

FIG. 12 (PRIOR ART)