Variable displacement vane pump and method of controlling the same

A variable displacement vane pump includes: a cam ring defining first and second fluid pressure chambers on both sides thereof; and a rotor mounted inside the cam ring, the rotor defining an annular chamber outside thereof. Arranged outside of the rotor, vanes divide the annular chamber into a plurality of pump chambers. A suction port is defined in a section of the annular chamber in which each of the pump chambers expands with the rotation of the rotor, while a discharge port is defined in a section of the annular chamber in which each of the pump chambers contracts with the rotation of the rotor. A first fluid passage is connected to one of the first and second fluid pressure chambers. A second fluid passage is connected to one of the suction port and the discharge port. An electromagnetic valve controls fluid communication between the first and second fluid passages.
Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates generally to variable displacement pumps, and more particularly to variable displacement vane pumps useful for power steering systems.

[0002] Japanese Patent Application Publication No. 2004-218430 shows a variable displacement vane pump including a rotor and a cam ring surrounding the rotor in which working fluid flows circumferentially between the rotor and the cam ring. The cam ring is mounted for swinging motion. As the cam ring is displaced to alter the shape of the space defined between the rotor and the cam ring, the discharge quantity of this pump varies. The swinging motion of the cam ring is controlled by a control valve through two opposed fluid pressure chambers. The control valve includes a pilot chamber for receiving a fluid pressure from a downstream portion of a discharge passage with respect to an orifice. Provided in a fluid passage extending between the second pilot chamber and a fluid tank, a solenoid valve controls the internal pressure of the pilot chamber by regulating the opening of the fluid passage. This causes a change in the position of the control valve, and thereby causes a change in the position of the cam ring through the fluid pressure chambers.

SUMMARY OF THE INVENTION

[0003] The variable displacement vane pump disclosed in Japanese Patent Application Publication No. 2004-218430 is confronted at least with the following problems. First, the cam ring starts to move after a delay from the time when the solenoid valve receives a drive signal, because the control valve operates at an intermediate stage. Second, the solenoid valve needs to have a sufficient capability to move against a high level of fluid pressure, because the solenoid valve is subject in the direction of movement to the high discharge pressures introduced into the control valve. This tends to increase the size and weight of the solenoid valve.

[0004] Accordingly, it is an object of the present invention to provide a variable displacement vane pump with high responsiveness and compact structure.

[0005] According to one aspect of the present invention, a variable displacement vane pump comprises: a pump body; a cam ring movably mounted within the pump body, the cam ring and the pump body defining first and second fluid pressure chambers therebetween, the first fluid pressure chamber having a volumetric capacity that increases when the cam ring moves toward a first end position; a second fluid pressure chamber having a volumetric capacity that increases when the cam ring moves toward a second end position; a third fluid passage hydraulically connected to one of the first and second fluid pressure chambers; a second fluid passage hydraulically connected to one of the suction port and the discharge port; and an electromagnetic valve hydraulically connected to the first and second fluid passages for controlling fluid communication therebetween.

[0006] According to another aspect of the invention, a variable displacement vane pump comprises: a pump body; a cam ring movably mounted within the pump body, the cam ring and the pump body defining first and second fluid pressure chambers therebetween, the first fluid pressure chamber having a volumetric capacity that increases when the cam ring moves toward a first end position, the second fluid pressure chamber having a volumetric capacity that increases when the cam ring moves toward a second end position; a rotor mounted inside the cam ring at least for rotation about an axis in a direction, the rotor defining an annular chamber outside thereof; a plurality of vanes arranged circumferentially at an outer radial periphery of the rotor for movement with the rotation of the rotor, the vanes extending radially and dividing the annular chamber into a plurality of pump chambers; a suction port defined in a first section of the annular chamber in which each of the pump chambers expands with the rotation of the rotor; a discharge port defined in a second section of the annular chamber in which each of the pump chambers contracts with the rotation of the rotor, the discharge port defining a third section of the annular chamber from the suction port to the discharge port along the direction of rotation of the rotor, the third section having a larger volumetric capacity when the cam ring is in the second end position than when the cam ring is in the first end position; a first fluid passage hydraulically connected to one of the first and second fluid pressure chambers; and an electromagnetic valve hydraulically connected to the third fluid passage for controlling fluid communication through the third fluid passage.

[0007] According to a further aspect of the invention,
a method of controlling a variable displacement vane pump for a vehicle, the variable displacement vane pump comprising: a pump body; a cam ring movably mounted within the pump body, the cam ring defining at least a pump chamber and a first fluid pressure chamber having an internal pressure acting on the cam ring; a suction port; a discharge port; a discharge passage downstream with respect to the discharge port, the discharge passage including an orifice; a control valve for controlling the internal pressure of the first fluid pressure chamber, the control valve operating in response to pressures from upstream and downstream portions of the discharge passage with respect to the orifice; an electromagnetic valve for controlling fluid communication among the first fluid pressure chamber, the suction port and the discharge port; a discharge port; a discharge passage downstream with respect to the orifice; an electromagnetic valve of the variable displacement vane pump in accordance with a fifth embodiment of the present invention.

FIG. 1 is an axial sectional view of a variable displacement vane pump in accordance with a first embodiment of the present invention.

FIG. 2 is a radial sectional view of the variable displacement vane pump of the first embodiment under condition that a cam ring is displaced maximally.

FIG. 3 is an enlarged longitudinal sectional view of a control valve of the variable displacement vane pump of the first embodiment.

FIG. 4 is an enlarged longitudinal sectional view of a solenoid valve of the variable displacement vane pump of the first embodiment.

FIG. 5 is a radial sectional view of a variable displacement vane pump in accordance with a first modification of the first embodiment.

FIG. 6 is a radial sectional view of a variable displacement vane pump in accordance with a second modification of the first embodiment.

FIG. 7 is a radial sectional view of a variable displacement vane pump in accordance with a second embodiment of the present invention.

FIG. 8 is a radial sectional view of a variable displacement vane pump in accordance with a modification of the second embodiment.

FIG. 9 is a radial sectional view of a variable displacement vane pump in accordance with a third embodiment of the present invention.

FIG. 10 is a radial sectional view of a variable displacement vane pump in accordance with a third modification of the third embodiment.

FIG. 11 is a radial sectional view of a variable displacement vane pump in accordance with a fourth embodiment of the present invention.

FIG. 12 is a radial sectional view of a variable displacement vane pump in accordance with a fourth modification of the fourth embodiment.

FIG. 13 is an axial sectional view of a variable displacement vane pump in accordance with a fifth embodiment of the present invention.

FIG. 14 is a radial sectional view of the variable displacement vane pump of the fifth embodiment under condition that a cam ring is displaced maximally.

FIG. 15 is a radial sectional view of the variable displacement vane pump of the fifth embodiment under condition that the cam ring is displaced minimally.

FIG. 16 is an axial sectional view of a variable displacement vane pump in accordance with a modification of the fifth embodiment.

FIG. 17 is a radial sectional view of a variable displacement vane pump in accordance with a modification of the sixth embodiment.

FIG. 18 is a radial sectional view of a variable displacement vane pump in accordance with a second modification of the sixth embodiment.

FIG. 19 is a radial sectional view of a variable displacement vane pump in accordance with a second modification of the sixth embodiment.

FIG. 20 is a radial sectional view of a variable displacement vane pump in accordance with a third modification of the sixth embodiment.

FIG. 21 is a radial sectional view of a variable displacement vane pump in accordance with a fourth modification of the sixth embodiment.

FIG. 22 is an axial sectional view of a variable displacement vane pump in accordance with a fifth modification of the sixth embodiment.

A right-handed rectangular coordinate system (xyz) is provided in the drawings. In this variable displacement vane pump, a controlled fluid pressure is introduced into a first fluid pressure chamber, while a suction pressure is introduced into a second fluid pressure chamber, as described below in detail.

A variable displacement vane pump 1 generally includes a drive shaft 2, a rotor 3, a cam ring 4, an adapter ring 5, a pump body 10, a control valve 200, and an electromagnetic valve 300 in the form of a solenoid valve. Cam ring 4 is movably mounted within pump body 10, defining first and second fluid pressure chambers A1 and A2. Rotor 3 is mounted inside cam ring 4 at least for rotation about an axis in a direction, defining an annular chamber outside thereof. The axis of rotor 3 extends in the x-direction, while the direction of rotation of rotor 3 is counterclockwise as viewed in FIG. 2. Drive shaft 2 is mounted on pump body 10 for rotation about its longitudinal axis, extending in the x-direction as shown in FIG. 2. Drive shaft 2 is drivingly connected to an engine through a pulley and a timing belt, and mechanically coupled to rotor 3 for rotation in synchronization with the rotation of the rotor 3.
Pump body 10 includes a first housing 11 and a second housing 12 as shown in FIG. 1. First housing 11 in the form of a cup has an open axial end facing in the positive x-direction. A pressure plate 6 in the form of a disc is mounted at the bottom 111 of first housing 11. Adapter ring 5, cam ring 4 and rotor 3 are mounted in a pump component accommodation section or space 112 defined inside the inner periphery of first housing 11 between pressure plate 6 and second housing 12. First housing 11 rotatably supports drive shaft 2. The axial height of adapter ring 5, cam ring 4 and rotor 3 are identical, forming flat and flush axial end faces. Pressure plate 6 is in fluid-tight contact with one axial end of adapter ring 5, cam ring 4 and rotor 3, while second housing 12 is in fluid-tight contact with the other axial end of adapter ring 5, cam ring 4 and rotor 3.

Second housing 12 is formed with a high-pressure introduction groove 9 in an axial end face 120 facing in the negative x-direction. High-pressure introduction groove 9 is disposed in a portion of axial end face 120 which is in constant contact with cam ring 4. High-pressure introduction groove 9 is hydraulically connected to a discharge port 122. Thus, the discharge pressure is introduced to the contact site between cam ring 4 and second housing 12. The discharge pressure acts substantially all over the annular contact site, equalizing the pressure applied to the contact site circumferentially.

Pressure plate 6 is formed with a suction port 62 and a discharge port 63 in an axial end face 61 facing in the positive x-direction, while second housing 12 is formed with a suction port 121 and a discharge port 122 in axial end face 120. Suction ports 62 and 121 are hydraulically connected to a suction passage IN. Suction passage IN has an opening connected to an outside suction pipe 14 leading to a fluid reservoir tank 15, the opening being disposed on the top of second housing 12 as viewed in FIG. 1. Discharge ports 63 and 122 are hydraulically connected to a discharge passage OUT. Discharge passage OUT has an opening on the top of first housing 11 as viewed in FIG. 1. Thus, working fluid is introduced into the annular chamber defined between rotor 3 and cam ring 4 through the suction ports 62 and 121, while the working fluid is discharged through the discharge ports 63 and 122. Suction passage IN is hydraulically connected to solenoid valve 300 through a fluid communication passage C2.

Adapter ring 5 is mounted radially outside of cam ring 4 within pump body 10. Adapter ring 5 in the form of an elliptical annular shape has a major axis substantially in the y-direction and a minor axis substantially in the z-direction. Adapter ring 5 is engaged with first housing 11 so that no rotation of adapter ring 5 is allowed with respect to first housing 11.

Cam ring 4 in the form of a perfect circular annular shape has an outer radial diameter substantially identical with the minor axis of adapter ring 5. Thus, when cam ring 4 is mounted in adapter ring 5, an annular chamber is defined therebetween. Cam ring 4 can move in the y-direction, that is, in the perpendicular direction to the axis of rotor 3 with respect to pump body 10.

A seal 50 is mounted at the top of an inner peripheral surface 53 of adapter ring 5 as viewed in FIG. 2. A pin 40 is mounted at the bottom of inner peripheral surface 53 as viewed in FIG. 2. Cam ring 4 is pivotally supported on pin 40 for swing motion within adapter ring 5. Pin 40 and seal 50 divide the annular chamber defined between cam ring 4 and adapter ring 5 into first fluid pressure chamber A1 and second fluid pressure chamber A2 radially inside adapter ring 5. First fluid pressure chamber A1 is located on the negative y side with respect to cam ring 4, while second fluid pressure chamber A2 is located on the positive y side. First fluid pressure chamber A1 has an internal pressure P1 acting on cam ring 4 in a direction to move the cam ring 4 toward a first end position, while second fluid pressure chamber A2 has an internal pressure P2 acting on cam ring 4 in a direction to move the cam ring 4 toward a second end position.

The outer radial peripheral surface of rotor 3 has a smaller diameter than the inner peripheral surface 41 of cam ring 4 so that the rotor 3 is mounted inside the cam ring 4. Even when cam ring 4 is displaced maximally, rotor 3 is out of contact with cam ring 4. A distance L is defined as a distance between the outer radial peripheral surface of rotor 3 and the inner peripheral surface 41 of cam ring 4 as shown in FIG. 2. On the left side of rotor 3 as viewed in FIG. 2, distance L is minimum when cam ring 4 is displaced maximally in the positive y-direction, while distance L is maximum when cam ring 4 is displaced maximally in the negative y-direction.

As shown in FIG. 2, a plurality of vanes 32 are arranged circumferentially at an outer radial periphery of rotor 3 for movement with the rotation of rotor 3, extending radially and dividing the annular chamber defined between rotor 3 and cam ring 4 into a plurality of pump chambers B. In this embodiment, rotor 3 is formed with a plurality of slots 31 at an outer radial periphery. Each slot 31 extends radially. Vanes 32 are inserted into respective slots 31 for back-and-forth longitudinal sliding movement. Each slot 31 includes a back pressure chamber 33 at the proximal end. A discharge pressure is introduced into each back pressure chamber 33 to urge the respective vane 32 in the radial outward direction. Pressure plate 6 has an axial end face 61 facing in the positive x-direction. Back pressure introduction grooves 64 and 124 are defined in axial end face 61 of pressure plate 6 and axial end face 120 of second housing 12, respectively. The discharge pressure for back pressure chamber 33 is introduced through the back pressure introduction grooves 64 and 124.

Each vane 32 has a radial length at least larger than the maximum of distance L so that the vane 32 constantly extends from slot 31 of rotor 3 to inner peripheral surface 41 of cam ring 4 independently of the relative geometrical relationship between rotor 3 and cam ring 4. Receiving the back pressure from back pressure chamber 33, vane 32 is constantly in pressed fluid-tight contact.
with inner peripheral surface 41 of cam ring 4.

[0041] Thus, each pump chamber B is defined fluid-tightly between rotor 3 and cam ring 4 by respective adjacent two vanes 32. When rotor 3 is positioned eccentrically with respect to cam ring 4, the volumetric capacity of each pump chamber B varies with the rotation of rotor 3.

[0042] Suction ports 62, 121, which are defined in pressure plate 6 and second housing 12, respectively, are defined in a section of the annular chamber defined between rotor 3 and cam ring 4 in which each pump chamber B expands with the rotation of rotor 3. Discharge ports 63, 122, which are defined in pressure plate 6 and second housing 12, respectively, are defined in a section of the annular chamber defined between rotor 3 and cam ring 4 in which each pump chamber B contracts with the rotation of rotor 3. Thus, the working fluid is introduced through the suction ports 62, 121 and discharged through the discharge ports 63, 122.

[0043] Pressure plate 6 is formed with a suction pressure introduction groove 65 in axial end face 61. Suction pressure introduction groove 65 is hydraulically connected to second fluid pressure chamber A2 for introducing a suction pressure Pin into second fluid pressure chamber A2.

[0044] Adapter ring 5 is formed with a radial through hole 51 at the right end as viewed in Fig. 2. First housing 11 is formed with a plug accommodation hole 114 at the right end as viewed in Fig. 2. A cup-shaped plug 70 is inserted into plug accommodation hole 114 and radial through hole 51 with a bottom face 73 facing in the negative y-direction. Plug accommodation hole 114 is enclosed by a lid 72. Plug 70 serves as a separator defining a third fluid pressure chamber A3 and second fluid pressure chamber A2 on both sides thereof, third fluid pressure chamber A3 having an internal pressure P3 acting on cam ring 4 in a direction to move cam ring 4 toward the second end position.

[0045] A spring 71 is retained in the recess of plug 70 for expanding and contracting in the y-direction. Spring 71 has one end attached to the bottom of plug 70 and the other end attached to lid 72, urging the plug 70 in the negative y-direction. Thus, plug 70 extends through the radial through hole 51 of adapter ring 5 so that the bottom 73 is in constant contact with cam ring 4, and urges the cam ring 4 in the negative y-direction. When cam ring 4 is in the right end position within adapter ring 5 as viewed in Fig. 2, the eccentricity of the center of cam ring 4 with respect to the axis of rotor 3 is minimum. When cam ring 4 is in the left end position within adapter ring 5 as viewed in Fig. 2, the eccentricity of the center of cam ring 4 with respect to the axis of rotor 3 is maximum. Accordingly, plug 70 urges the cam ring 4 in a direction to increase the displacement of cam ring 4 with respect to rotor 3. The outer circumferential periphery 74 of plug 70 is in fluid-tight sliding contact with plug accommodation hole 114 so as to fluid-tightly separate the second fluid pressure chamber A2 from outside of pump body 10.

[0046] FIG. 3 shows the detailed construction of control valve 200. Control valve 200 is a differential-pressure-actuated valve. Control valve 200 is accommodated in a valve accommodation hole 115 extending in first housing 11 in the y-direction. Control valve 200 includes a spool 210 as a valve element and a relief valve 220. Valve element 210 in the form of a cup has an opening facing in the positive y-direction. A valve-element-biasing spring 230 is mounted at the bottom of valve accommodation hole 115 for urging the valve element 210 in the negative y-direction. Relief valve 220 is mounted in the center bore of valve element 210 for fluid-tightly sliding on the inner periphery 211 of valve element 210. Valve element 210 includes a first sliding portion 213 and a second sliding portion 214 at the outer periphery 212. First sliding portion 213 and second sliding portion 214 are in fluid-tight sliding contact with valve accommodation hole 115. First sliding portion 213 and second sliding portion 214 each extend circumferentially around the outer periphery 212 and have a larger diameter than the other portions of the outer periphery 212. This defines a recess 215 extending circumferentially around the outer periphery 212 between first sliding portion 213 and second sliding portion 214. Thus, the inner space of valve accommodation hole 115 is divided into three sections, i.e., as viewed in FIG. 3, a first fluid chamber D1 defined on the left side of first sliding portion 213, a second fluid chamber D2 defined on the right side of recess 215, and a third fluid chamber D3 defined in recess 215 between first sliding portion 213 and second sliding portion 214.

[0047] First fluid chamber D1 is hydraulically connected to discharge ports 63 and 122 through a fluid passage 21, while second fluid chamber D2 is hydraulically connected to discharge ports 63 and 122 through a fluid passage 22. It is noted that the fluid passages 21 and 22 are parts of discharge passage OUT. Fluid passage 21 includes no orifice, while fluid passage 22 includes an orifice 8. That is, first fluid chamber D1 is hydraulically connected to an upstream portion of discharge passage OUT with respect to orifice 8, while second fluid chamber D2 is hydraulically connected to a downstream portion of discharge passage OUT with respect to orifice 8. Thus, a discharge pressure Pout is introduced into first fluid chamber D1, while a downstream discharge pressure Pfb is introduced into second fluid chamber D2. Downstream discharge pressure Pfb, which is defined as a pressure in a downstream portion of fluid passage 22 with respect to orifice 8, is lower than discharge pressure Pout by a decrease due to orifice 8. Incidentally, in other situations where the pressure decrease due to orifice 8 is insignificant, downstream discharge pressure Pfb may be referred to simply as “discharge pressure”.

[0048] Third fluid chamber D3 is hydraulically connected to suction passage IN through a fluid passage 23 so that a suction pressure Pin is introduced thereinto. Third fluid chamber D3 is also hydraulically connected to the inner space of valve element 210 through a radial hole 216 formed in recess 215. Thus, second fluid chamber
D2 and third fluid chamber D3 are hydraulically separated from each other by relief valve 220.

[0049] As shown in FIG. 3, adapter ring 5 is formed with a communication hole 52 near the top on the negative y side of seal 50, while first housing 11 is formed with a fluid passage 113. Control valve 200 is hydraulically connected to first fluid pressure chamber A1 through the communication hole 52 and fluid passage 113. Fluid passage 113 is also hydraulically connected to solenoid valve 300 through a fluid communication passage (or fluid passage) C1.

[0050] Fluid passage 113 has an opening 113a in the side wall of valve accommodation hole 115. While the pump is inoperative, opening 113a faces the recess 215 of valve element 210 so that the fluid passage 113 is hydraulically connected to third fluid chamber D3. When valve element 210 is displaced in the positive y-direction so that the first sliding portion 213 is displaced ahead of opening 113a in the positive y-direction, the fluid passage 113 is hydraulically connected to first fluid chamber D1.

[0051] Valve element 210 is subject to a force due to the internal pressure of first fluid chamber D1 in the positive y-direction, Fv1, a force due to the internal pressure of second fluid chamber D2 in the negative y-direction, Fv2, and a force due to valve-element-biasing spring 230 in the negative y-direction, Fc1. The condition of equilibrium is expressed by the following equation.

\[ Fv1 = Fv2 + Fc1 \]

Accordingly, valve element 210 travels in the negative y-direction, when equation (a) is established.

\[ Fv1 \leq Fv2 + Fc1 \]  \hspace{1cm} (a)

Under this condition, opening 113a is brought to be on the positive y side of first sliding portion 213 so that the fluid passage 113 is hydraulically connected to third fluid chamber D3. On the other hand, valve element 210 travels in the positive y-direction, when equation (b) is established.

\[ Fv1 > Fv2 + Fc1 \]  \hspace{1cm} (b)

Under this condition, opening 113a is brought to be on the negative y side of first sliding portion 213 so that the fluid passage 113 is hydraulically connected to first fluid chamber D1. The conditions (a) and (b) may be adjusted by varying the characteristics of the force of valve-element-biasing spring 230, Fc1.

[0052] Relief valve 220 includes a valve seat 221, a ball valve 222, a spring retainer 223 and relief valve spring 224. These components are arranged in the negative y-direction in order of valve seat 221, ball valve 222, spring retainer 223 and relief valve spring 224. Valve seat 221 is mounted in the center bore of valve element 210 for longitudinal sliding movement. Valve seat 221 fluid-tightly defines part of second fluid chamber D2. Valve seat 221 includes a through hole 221a extending in the y-direction. A force due to the fluid pressure from second fluid chamber D2, Fv2, acts on ball valve 222 via through hole 221a. Relief valve spring 224 has an end connected to the bottom 217 of the center bore of valve element 210, urging the ball valve 222 in the positive y-direction. Thus, ball valve 222 is subject to the force due to the internal pressure of second fluid chamber D2 in the negative y-direction, Fv2, and the force due to relief valve spring 224 in the positive y-direction, Fc2.

[0053] When equation (c) is satisfied, ball valve 222 is in contact with valve seat 221 to close the through hole 221a, shutting off the second fluid chamber D2 and third fluid chamber D3 from one another.

\[ Fv2 \leq Fc2 \]  \hspace{1cm} (c)

On the other hand, when equation (d) is satisfied, ball valve 222 moves out of contact with valve seat 221, hydraulically connecting the second fluid chamber D2 and third fluid chamber D3 to one another.

\[ Fv2 > Fc2 \]  \hspace{1cm} (d)

Thus, third fluid chamber D3 is hydraulically connected to both of suction passage IN and second fluid chamber D2. The conditions (c) and (d) may be adjusted by varying the characteristics of the biasing force of relief valve spring 224, Fc2.

[0054] The following describes how control valve 200 controls the internal pressure of first fluid chamber D1. (i) While first fluid chamber D1 is hydraulically connected to fluid passage 113 (when equation (b) is satisfied), first fluid pressure chamber A1 is hydraulically connected to first fluid chamber D1 through the fluid passage 113 and communication hole 52 so that the discharge pressure Pout (from the upstream portion of fluid passage 22 with respect to orifice 8) is introduced into first fluid pressure chamber A1. (ii) While third fluid chamber D3 is hydraulically connected to fluid passage 113 (when equation (a) is satisfied), first fluid pressure chamber A1 is hydraulically connected to third fluid chamber D3. The introduced pressure is dependent on whether relief valve 220 is open or closed. (ii-1) While relief valve 220 is closed under the condition of (ii) (when equations (a) and (c) are satisfied), second fluid chamber D2 and third fluid chamber D3 are shut off from one another so that the suction pressure Pin is introduced into first fluid pressure chamber A1. (ii-
2) While relief valve 220 is opened under the condition of (ii) (when equations (a) and (d) are satisfied), second fluid chamber D2 and third fluid chamber D3 is hydraulically connected to one another. At this time, the internal pressure of third fluid chamber D3 is a mixed pressure Pm produced based on suction pressure Pin and downstream discharge pressure Pfb. This mixed pressure Pm is introduced into first fluid pressure chamber A1. It is to be noted that the equation of (Pin < Pm < Pout) is satisfied. In summary, the pressure introduced from control valve 200 into first fluid pressure chamber A1, or controlled valve pressure Pv, is equal to discharge pressure Pout under condition of (i), suction pressure Pin under condition of (ii-1), and mixed pressure Pm under condition of (ii-2).

[0055] Alternatively, controlled pressure Pv may be introduced into second fluid pressure chamber A2, not to first fluid pressure chamber A1.

[0056] A section of the annular chamber defined between rotor 3 and cam ring 4 from suction ports 62 and 121 to discharge ports 63 and 122 along the direction of rotation of rotor 3 has a larger volumetric capacity when cam ring 4 is in the second end position than when cam ring 4 is in the first end position. Cam ring 4 is subject to a force in the positive y-direction due to the internal pressure P1 of first fluid pressure chamber A1, F1, and a force in the negative y-direction due to the internal pressure P2 of second fluid pressure chamber A2 and due to spring 71, F2. While F1 > F2, cam ring 4 swings clockwise about pin 40 as viewed in FIG. 2 or moves in the positive y-direction. This increases the volumetric capacity of a pump chamber Byp closer to second fluid pressure chamber A2, and reduces that of a pump chamber Byn closer to second fluid pressure chamber A2. As the volumetric capacity of pump chamber Byp decreases, the quantity of working fluid flowing from suction ports 62 and 121 to discharge ports 63 and 122 per time decreases and the discharge pressure falls. Then, when the internal pressure of first fluid pressure chamber A1, P1, falls so that the resultant force F2 in the negative y-direction is dominant, cam ring 4 swings back counterclockwise as viewed in FIG. 2, or moves back in the negative y-direction.

[0057] When the forces F1 and F2 in the positive and negative y-directions are in balance, cam ring 4 is held stationary. When cam ring 4 is positioned concentrically with rotor 3, the volumetric capacity of pump chamber Byp is identical with that of pump chamber Byn so that both of the suction pressure and the discharge pressure are equal to zero. Upon this, the internal pressure of first fluid pressure chamber A1, P1, also becomes zero so that the cam ring 4 is urged in the negative y-direction by spring 71. Thus, the displacement of cam ring 4 with respect to rotor 3 is automatically adjusted so that the difference between the discharge pressures on the upstream and downstream sides of orifice 8.

[0058] Solenoid valve 300 is disposed in a fluid communication passage C hydraulically connecting the first fluid pressure chamber A1 to suction passage IN. Fluid communication passage C includes a fluid communication passage C1 hydraulically connecting the solenoid valve 300 to first fluid pressure chamber A1, and a fluid communication passage C2 hydraulically connecting the solenoid valve 300 to suction passage IN. Solenoid valve 300 is accommodated in a valve accommodation hole 117 defined in first housing 11. Valve accommodation hole 117 is defined on the negative y side and the positive z side of the axis of rotor 3, extending in the y direction. Solenoid valve 300 selectively provides or inhibits fluid communication between first fluid pressure chamber A1 and suction passage IN.

[0059] FIG. 4 shows the detailed construction of solenoid valve 300. Solenoid valve 300 generally includes a valve mechanism disposed between communication passages C1 and C2, and an electromagnetic actuator for controlling the valve mechanism. Solenoid valve 300 includes a sleeve 310, a spool 320, a spring 330, and a coil 360. Rod 340, plunger 350 and coil 360 are henceforth collectively referred to as "solenoide SOL". Solenoid SOL serves as the electromagnetic actuator.

[0060] Sleeve 310 in the form of a cup is accommodated in valve accommodation hole 117 with the bottom facing the bottom of valve accommodation hole 117. Spool 320 and spring 330 are accommodated in the center of the sleeve 310. Spring 330 has one axial end connected to the bottom 311 of sleeve 310, urging the spool 320 in the negative y-direction.

[0061] Spool 320 is mounted in the center bore of the sleeve 310 in such a manner to be in substantially fluid-tight sliding contact with the inner circumferential periphery of sleeve 310. A fourth fluid chamber D4 is defined between spool 320 and the bottom 311 of sleeve 310. Sleeve 310 is formed with a groove 313 extending around the outer periphery 312, and two radial holes 314 and 314 leading to fluid communication passage C2. Sleeve 310 is formed with a longitudinal hole 315 extending through the bottom 311 in the y-direction so that the fourth fluid chamber D4 is hydraulically connected to fluid communication passage C1.

[0062] Spool 320 is in the form of a cylinder. Spool 320 is formed with a recess 321 in one axial end face facing in the positive y-direction. Spring 330 has one end connected to recess 321 of spool 320 and the other end connected to the bottom 311 of sleeve 310. Spool 320 is also formed with a through hole 322 extending in the y-direction, and a radial hole 323 extending in the z-direction. Thus, radial hole 323 is hydraulically connected to recess 321 via hole 322.

[0063] When spool 320 moves in the y-direction so that the radial hole 314 of sleeve 310 is hydraulically connected to radial hole 323 of spool 320, fluid communication passage C1 is hydraulically connected to fluid communication passage C2 through the radial hole 314, radial hole 323 and fourth fluid chamber D4.

[0064] Rod 340 is fixedly coupled to plunger 350. En-
erged by coil 360, plunger 350 moves the rod 340 in the y direction. Rod 340 has a longitudinal end 341 in contact with a longitudinal end 324 of spool 320 so as to move the spool 320 in the positive y-direction. At longitudinal end 324 of spool 320, the opening of through hole 322 is defined so as not to overlap with the portion in contact with rod 340. This ensures that the rod 340 effectively presses the spool 320.

[0065] While the thrust of plunger 350 is above the elastic force of spring 330, spool 320 moves in the positive y-direction. On the other hand, when plunger 350 is de-energized, spool 320 is urged in the negative y-direction by spring 330 to move in the negative y-direction so that the fluid communication passage C1 is hydraulically disconnected from fluid communication passage C2. When the thrust of plunger 350 is increased, radial hole 323 of spool 320 overlaps with radial hole 314 of sleeve 310 so that the fluid communication passage C1 is hydraulically connected to fluid communication passage C2.

[0066] The flow rate of working fluid through the fluid communication passage C is controlled by adjusting the thrust of solenoid SOL and thereby adjusting the area in which radial hole 314 of sleeve 310 overlaps with radial hole 323 of spool 320. Thus, solenoid valve 300 functions as a normally closed linear solenoid valve. Solenoid valve 300 is closed during failed conditions thereof. Specifically, while solenoid SOL is subject to malfunctions or is de-energized, the valve mechanism of solenoid valve 300 is closed. In such situations, the variable displacement vane pump operates only depending on control valve 200 without any adverse effect resulting from malfunction of solenoid valve 300.

[0067] As described above, while solenoid valve 300 is in an open state, fluid communication passage C is opened so as to hydraulically connect the first fluid pressure chamber A1 to suction passage IN. When the internal pressure of first fluid pressure chamber A1, P1, is higher than suction pressure Pin, the working fluid flows from first fluid pressure chamber A1 to suction passage IN through the solenoid valve 300. When P1=Pin, the working fluid does not flow therebetween.

[0068] In summary, while first fluid pressure chamber A1 is hydraulically connected to third fluid chamber D3 of control valve 200 and relief valve 220 is closed (when equations (a) and (c) are satisfied), the internal pressure of first fluid pressure chamber A1, P1, is held equal to suction pressure Pin, even if solenoid valve 300 is opened. On the other hand, in the other cases (at least one of equations (a) and (c) is unsatisfied), first fluid pressure chamber A1 is hydraulically connected to first fluid chamber D1 or second fluid chamber D2 so that the internal pressure of first fluid pressure chamber A1, P1, is equal to discharge pressure Pout or mixed pressure Pm. Accordingly, pressure P1 is higher than suction pressure Pin. Therefore, while solenoid valve 300 is in an open state, pressure P1 falls. The decrease in pressure P1 is controlled by adjusting the degree of opening of solenoid valve 300.

[0069] In this embodiment, the internal pressure of first fluid pressure chamber A1, P1, is controlled basically by control valve 200 and additionally by solenoid valve 300. This results in a variable displacement vane pump with improved responsiveness. The thus-described simple pressure control of solenoid valve 300 is sufficient, because control valve 200 contributes to the basic pressure control.

[0070] In this embodiment, solenoid valve 300 controls only one of the internal pressure of first fluid pressure chamber A1, P1, and the internal pressure of second fluid pressure chamber A2, P2. Accordingly, solenoid valve 300 has a simple and compact structure. The construction that the suction pressure Pin (low pressure) is constantly introduced into second fluid pressure chamber A2, is advantageous for minimizing leaking of working fluid from second fluid pressure chamber A2 to suction ports 62 and 121. The discharge quantity can be suitably controlled depending on the vehicle operating state.

[0071] FIG. 5 shows a variable displacement vane pump in accordance with a first modification of the first embodiment. In the first embodiment, fluid communication passage C1 has an opening in fluid passage 113. In this modification, fluid communication passage C1 extends straight through the adapter ring 5 to first fluid pressure chamber A1.

[0072] FIG. 6 shows a variable displacement vane pump in accordance with a second modification of the first embodiment. In this modification, fluid communication passage C2 is replaced by a fluid communication passage C2'. Fluid communication passage C2' hydraulically connects the solenoid valve 300 to discharge passage OUT. Specifically, fluid communication passage C2' has an opening in an upstream portion of fluid passage 22 with respect to orifice 8 so that the discharge pressure Pout is introduced to solenoid valve 300. Solenoid valve 300 introduces discharge pressure Pout into first fluid pressure chamber A1 through the fluid communication passage C1.

[0073] On the other hand, control valve 200 introduces first fluid pressure chamber A1 one of discharge pressure Pout (in the case of (i)), suction pressure Pin (in the case of (ii-1)), and mixed pressure Pm (in the case of (ii-2)). Accordingly, while suction pressure Pin or mixed pressure Pm is introduced into first fluid pressure chamber A1, the internal pressure of first fluid pressure chamber A1, P1, can be increased by opening the solenoid valve 300 to introduce the discharge pressure Pout thereinto.

[0074] Although, in the foregoing embodiments, the internal pressure of first fluid pressure chamber A1 is controlled by control valve 200 and solenoid valve 300, the internal pressure of second fluid pressure chamber A2 may be controlled by control valve 200 and solenoid valve 300 with introducing the suction pressure Pin into first fluid pressure chamber A1.

[0075] FIG. 7 shows a variable displacement vane
pump in accordance with a second embodiment of the present invention. The second embodiment differs from the first modification of the first embodiment in that the control valve 200 controls both of first fluid pressure chamber A1 and second fluid pressure chamber A2 in the second embodiment.

[0076] Specifically, adapter ring 5 is formed with a communication hole 54 disposed near the top on the positive y side of seal 50, while first housing 11 is formed with a fluid passage 119. Second fluid pressure chamber A2 is hydraulically connected to control valve 200 through the fluid pressure chamber communication hole 54 and fluid passage 119. Fluid passage 119 has an opening 119a in the side wall of valve accommodation hole 115. While the pump is inoperative, opening 119a faces the second fluid chamber D2 of control valve 200 so as to introduce the downstream discharge pressure Pfb into second fluid pressure chamber A2. When valve element 210 is displaced in the positive y-direction so that the second sliding portion 214 is displaced ahead of opening 119a in the positive y-direction, fluid passage 119 is hydraulically connected to third fluid chamber D3. As described above, the internal pressure of third fluid chamber D3 is equal to suction pressure Pin while relief valve 220 is closed, and is equal to mixed pressure Pm while relief valve 220 is opened. Thus, control valve 200 controls the internal pressure of second fluid pressure chamber A2, P2, by introducing thereinto one of pressures Pfb, Pin and Pm. In this embodiment, both of first fluid pressure chamber A1 and second fluid pressure chamber A2 are subject to high pressures. This stabilizes the movement of cam ring 4.

[0077] FIG. 8 shows a variable displacement vane pump in accordance with a modification of the second embodiment. In this modification, fluid communication passage C2 is replaced by a fluid communication passage C2' as in the second modification of the first embodiment. Fluid communication passage C2' hydraulically connects the solenoid valve 300 to discharge passage OUT. Specifically, fluid communication passage C2' has an opening in an upstream portion of fluid passage 22 with respect to orifice 8 so that the discharge pressure Pout is introduced to solenoid valve 300. Solenoid valve 300 introduces the discharge pressure Pout into first fluid pressure chamber A1 through the fluid communication passage C1.

[0078] FIG. 9 shows a variable displacement vane pump in accordance with a third embodiment of the present invention. The third embodiment is the same as the first embodiment except the following constructions. In this modification, a surface of adapter ring 5 for supporting the bottom of cam ring 4, represented by "N", is inclined so that the z coordinate decreases with increase in the y coordinate as shown in FIG. 9. A space defined by plug 70 and lid 72, referred to as "third fluid pressure chamber A3", is hydraulically connected to third fluid chamber D3 of control valve 200 so that the controlled valve pressure Pv is introduced into third fluid pressure chamber A3. The internal pressure of third fluid pressure chamber A3, P3, serves to press the cam ring 4 in the negative y-direction through the bottom 73 of plug 70. Third fluid pressure chamber A3 is hydraulically connected to suction passage IN through the solenoid valve 300. Thus, both of control valve 200 and solenoid valve 300 control the internal pressure of third fluid pressure chamber A3, P3.

[0079] Specifically, solenoid valve 300 is hydraulically connected to a fluid communication passage C3 and fluid communication passage C4. Fluid communication passage C3 is hydraulically connected to third fluid pressure chamber A3. Fluid communication passage C4 is hydraulically connected to suction passage IN.

[0080] As shown in FIG. 9, an imaginary line K-K is defined as a strait line connecting a midpoint M1 and a midpoint M2, where midpoint M1 is defined as a midpoint between the terminating end of suction ports 62 and 121 to the beginning end of discharge ports 63 and 122 along the direction of rotation of rotor 3, and midpoint M2 is defined as a midpoint between the terminating end of discharge ports 63 and 122 to the beginning end of suction ports 62 and 121 along the direction of rotation of rotor 3. Surface N of adapter ring 5 is inclined with respect to imaginary line K-K so that the distance between surface N and imaginary line K-K increases with moving from midpoint M1 to midpoint M2 as shown in FIG. 9.

[0081] As discharge pressure Pout increases, cam ring 4 is increasingly pressed down in the negative z-direction due to the balance between pump chambers B. The provision of surface N of adapter ring 5 is effective for raising the z position of cam ring 4 under condition that the cam ring 4 is displaced largely in the negative y-direction (discharge pressure Pout is high), and conversely for lowering the z position of cam ring 4 under condition that the displacement of cam ring 4 in the negative y-direction is small (discharge pressure Pout is low). This is effective for canceling the movement of cam ring 4 in the negative z-direction due to discharge pressure Pout, and thereby for minimizing oscillations and noises over low to high rotation regions.

[0082] Cup-shaped plug 70 is mounted in plug accommodation hole 114 of first housing 11 for longitudinal sliding movement in the y-direction in such a manner to maintain fluid-tight contact between the outer periphery of plug 70 and the inner periphery of plug accommodation hole 114. Lid 72 fluid-tightly closes the opening of plug accommodation hole 114. Thus, third fluid pressure chamber A3 is defined in plug accommodation hole 114 between lid 72 and the bottom of plug 70. Spring 71 is retained in the recess of plug 70 for expanding and contracting in the y-direction. Spring 71 has one end attached to the bottom of plug 70 and the other end attached to lid 72, urging the plug 70 in the negative y-direction. Thus, plug 70 extends through the radial through hole 51 of adapter ring 5 so that the bottom 73 is in constant contact with cam ring 4, and urges the cam ring 4 in the negative y-direction. The outer circumferential periphery 74 of plug...
300 is in an open state, third fluid pressure chamber A3 and from third fluid pressure chamber A3.

[0083] First housing 11 is formed with a fluid passage 24 hydraulically connecting the fluid communication passage C3 to control valve 200. Fluid passage 24 has an opening 24a in a portion of the side wall of valve accommodation hole 115 which is closed by second sliding portion 214 of valve element 210 while the pump is inoperative. When discharge pressure Pout arises by operation of the pump, the difference in internal pressure between first fluid chamber D1 and second fluid chamber D2, which is the difference between discharge pressure Pout and downstream discharge pressure Pfb, presses the valve element 210 to travel in the positive y-direction. Upon this, opening 24a of fluid passage 24 is relatively displaced to face the third fluid chamber D3, hydraulically connecting the third fluid chamber D3 to third fluid pressure chamber A3 so that the internal pressure of third fluid pressure chamber A3, P3, is set equal to the internal pressure of third fluid chamber D3, Pv3. As described in the first embodiment, the internal pressure of third fluid chamber D3, Pv3, is equal to suction pressure Pin while relief valve 220 is closed, and is equal to mixed pressure Pm based on the suction pressure Pin and downstream discharge pressure Pfb while relief valve 220 is opened. Since mixed pressure Pm is higher than suction pressure Pin, third fluid pressure chamber A3 is effective for preventing the cam ring 4 from excessively moving in the positive y-direction. Thus, solenoid valve 300 controls the displacement of cam ring 4 by controlling the internal pressure of third fluid pressure chamber A3.

[0084] In the third embodiment, solenoid valve 300 is disposed on the positive y side and on the positive z side of adapter ring 5 in first housing 11 as shown in FIG. 9. Solenoid valve 300 is hydraulically connected to third fluid pressure chamber A3 through the fluid communication passage C3, and to suction passage IN through the fluid communication passage C4. Thus, third fluid pressure chamber A3 is connected to suction passage IN through the solenoid valve 300. Solenoid valve 300 selectively connects and disconnects the third fluid pressure chamber A3 to and from suction passage IN. While the internal pressure of third fluid pressure chamber A3 is equal to mixed pressure Pm (higher than suction pressure Pin), the opening operation of solenoid valve 300 allows the working fluid within third fluid pressure chamber A3 to flow out to suction passage IN, reducing the internal pressure of third fluid pressure chamber A3, P3.

[0085] FIG. 10 shows a variable displacement vane pump in accordance with a modification of the third embodiment. In this modification, solenoid valve 300 is hydraulically connected to discharge passage OUT through a fluid communication passage C4'. While solenoid valve 300 is in an open state, third fluid pressure chamber A3 is hydraulically connected to discharge passage OUT. Control valve 200 introduces into third fluid pressure chamber A3 selectively one of suction pressure Pin and mixed pressure Pm, both of which are lower than discharge pressure Pout. Thus, while solenoid valve 300 is in an open state, discharge pressure Pout is introduced into third fluid pressure chamber A3. This increases the internal pressure of third fluid pressure chamber A3, increasing the force imposed on cam ring 4 in the negative y-direction. Thus, the displacement of cam ring 4 can be adjusted by solenoid valve 300.

[0086] FIG. 11 shows a variable displacement vane pump in accordance with a fourth embodiment of the present invention. The fourth embodiment is the same as the third embodiment except the following constructions. In the fourth embodiment, third fluid pressure chamber A3 is hydraulically connected to second fluid chamber D2 of control valve 200, not to third fluid chamber D3.

[0087] As shown in FIG. 11, first housing 11 is formed with a fluid passage 25 hydraulically connecting the fluid communication passage C3 to control valve 200. Fluid passage 25 has an opening 25a in a portion of the side wall of valve accommodation hole 115. Opening 25a constantly faces the second fluid chamber D2 independently of the position of valve element 210 of control valve 200. Thus, third fluid pressure chamber A3 is constantly connected to second fluid chamber D2 of control valve 200 so that the internal pressure of second fluid chamber D2, which is equal to downstream discharge pressure Pfb, is constantly introduced into third fluid pressure chamber A3. Further, solenoid valve 300 selectively connects and disconnects the third fluid pressure chamber A3 to and from suction passage IN, reducing the internal pressure of third fluid pressure chamber A3, P3. The foregoing is achieved by the provision of the simple and compact solenoid valve which directly controls the internal pressure of third fluid pressure chamber A3, P3, with improved responsiveness. Thus, the discharge quantity can be controlled on the basis of the operating conditions.

[0088] FIG. 12 shows a variable displacement vane pump in accordance with a modification of the fourth embodiment. In this modification, solenoid valve 300 is hydraulically connected to discharge passage OUT through a fluid communication passage C4a. Solenoid valve 300 selectively connects and disconnects the third fluid pressure chamber A3 to and from discharge passage OUT. Control valve 200 constantly introduces downstream discharge pressure Pfb into third fluid pressure chamber A3. While solenoid valve 300 is in an open state, the internal pressure of third fluid pressure chamber A3 is increased because downstream discharge pressure Pfb is lower than discharge pressure Pout.

[0089] FIGS. 13, 14 and 15 show a variable displacement vane pump in accordance with a fifth embodiment of the present invention. The fifth embodiment differs from the first embodiment in that the solenoid valve 300 is disposed close to suction passage IN, and solenoid valve 300 is hydraulically connected to first fluid pressure chamber A1 through a fluid communication passage C5.
extending in the axis of rotor 3.

[0090] As shown in FIG. 13, solenoid valve 300 is arranged in first housing 11 on the positive x side and on the positive z side with respect to rotor 3, close to the opening of suction passage IN. Solenoid valve 300 is hydraulically connected to first fluid pressure chamber A1 through a fluid communication passage C5 extending in the axis of rotor 3. A fluid communication passage C6 hydraulically connects the solenoid valve 300 to suction passage IN. Thus, solenoid valve 300 is disposed in fluid communication passage C including the fluid communication passage C5 and fluid communication passage C6.

[0091] As shown in FIGS. 14 and 15, the fluid communication passage C5 has an opening C5a in a portion of second housing 12 such that, independently of the position of cam ring 4, at least part of opening C5a is constantly open to first fluid pressure chamber A1 and thereby the fluid communication passage C5 is constantly connected to first fluid pressure chamber A1. Alternatively, opening C5a may be defined in the other axial end surface of first fluid pressure chamber A1, i.e. in the pressure plate 6. The thus-arranged opening C5a allows the solenoid valve 300 to constantly operate with high responsiveness.

[0092] According to the fifth embodiment, the variable displacement vane pump is constructed compact, because the components outside of pump body 10 are corrected close to one another. The relationship among control valve 200, first fluid pressure chamber A1 and second fluid pressure chamber A2 may be modified as described in the second, third and fourth embodiments.

[0093] FIG. 16 shows a variable displacement vane pump in accordance with a modification of the fifth embodiment. In this modification, solenoid valve 300 has a longitudinal axis perpendicular to the axes of rotor 3 and drive shaft 2. Solenoid valve 300 is mounted outside of pump body 10, and arranged close to the opening of suction passage IN and first fluid pressure chamber A1. The pulley, when attached to drive shaft 2, extends in the radial directions from drive shaft 2. Accordingly, vane pump 1 with the pulley needs a layout space extending longer than pump body 10 in the z direction. The variable displacement vane pump of this embodiment has a compact size in the x direction, without unnecessary extension of the radial sizes, because the layout space for the pulley is also available for solenoid valve 300.

[0094] FIG. 17 shows a variable displacement vane pump in accordance with a sixth embodiment of the present invention. The sixth embodiment differs from the preceding embodiments as follows. In this embodiment, the variable displacement vane pump includes no control valve 200.

[0095] A solenoid valve 300' is hydraulically connected to suction ports 62 and 121 through a fluid communication passage C8. Solenoid valve 300' is also hydraulically connected to first fluid pressure chamber A1 through the communication hole 52 formed in adapter ring 5 and a fluid communication passage C7 formed in first housing 11. Further, solenoid valve 300' is hydraulically connected to discharge passage OUT through a fluid communication passage C9 formed in first housing 11. Thus, solenoid valve 300' is disposed in a passage including fluid communication passages C7, C8 and C9.

[0096] Second fluid pressure chamber A2 is hydraulically connected to discharge passage OUT through the fluid passage 26 and fluid pressure chamber communication hole 54. Accordingly, discharge pressure Pout is constantly introduced into second fluid pressure chamber A2. Discharge passage OUT includes an orifice 7 between fluid communication passage C9 and fluid passage 26.

[0097] Solenoid valve 300' includes a spool 320', a spring 330', rod 340, plunger 350 and coil 360. No sleeve 310 is provided in this embodiment.

[0098] Spool 320' is generally in the form of a cylinder. Spool 320' is accommodated in a valve accommodation hole 117' for fluid-tight sliding contact with valve accommodation hole 117'. Valve accommodation hole 117' has a longitudinal end 117'a' on the positive y side and another longitudinal end 117'b' on the negative y side. A fifth fluid chamber D5' is defined between spool 320' and longitudinal end 117'a' of valve accommodation hole 117'. Spring 330' has an end connected to longitudinal end 117'a' to urge the spool 320' in the negative y-direction.

[0099] On the other hand, a fourth fluid chamber D4' is defined between one longitudinal end 321' of spool 320' and longitudinal end 117'b' of valve accommodation hole 117'. Fluid communication passage C8 has an opening C8a in the side wall of fourth fluid chamber D4'. Fluid communication passage C8 is constantly connected to fourth fluid chamber D4' independently of the position of spool 320'. Fluid communication passage C7 has an opening C7a in the side wall of valve accommodation hole 117'on the positive y side with respect to opening C8a. Further, fluid communication passage C9 has an opening C9a in the side wall of valve accommodation hole 117', opposite to opening C7a. Spool 320' includes a groove 323' in the radial outer circumferential surface 322', groove 323' extending all around the circumference.

[0100] When spool 320' is displaced in the negative y-direction, opening C7a of fluid communication passage C7 is hydraulically connected to opening C8a of fluid communication passage C8 through the groove 323'. On the other hand, when spool 320' is displaced in the positive y-direction, opening C7a of fluid communication passage C7 is hydraulically connected to opening C9a of fluid communication passage C9 through the groove 323'. Wherever spool 320' is positioned, opening C8a of fluid communication passage C8 is hydraulically separated from opening C9a of fluid communication passage C9.

[0101] Thus, solenoid valve 300' hydraulically connects the fluid communication passage C7 selectively to one of fluid communication passages C8 and C9, so as to hydraulically connect the first fluid pressure chamber.
A variable displacement vane pump comprising:

1. A pump body (10);
2. A cam ring (4) movably mounted within the pump body (10), the cam ring (4) and the pump body (10) defining first and second fluid pressure chambers (A1, A2) therebetween, the first fluid pressure chamber (A1) having a volumetric capacity that increases when the cam ring (4) moves toward a first end position, the second fluid pressure chamber (A2) having a volumetric capacity that increases when the cam ring (4) moves toward a second end position;
3. A rotor (3) mounted inside the cam ring (4) at least for rotation about an axis in a direction, the rotor (3) defining an annular chamber outside thereof;
4. A plurality of vanes (32) arranged circumferen-
tially at an outer radial periphery of the rotor (3) for movement with the rotation of the rotor (3), the vanes (32) extending radially and dividing the annular chamber into a plurality of pump chambers (B); a suction port (62, 121) defined in a first section of the annular chamber in which each of the pump chambers (B) expands with the rotation of the rotor (3); a discharge port (63, 122) defined in a second section of the annular chamber in which each of the pump chambers (B) contracts with the rotation of the rotor (3); the vanes (32) extending radially and dividing the annular chamber into a plurality of pump chambers (B); a suction port (62, 121) defined in a first section of the annular chamber in which each of the pump chambers (B) expands with the rotation of the rotor (3); a discharge port (63, 122) defined in a second section of the annular chamber in which each of the pump chambers (B) contracts with the rotation of the rotor (3); the vanes (32) extending radially and dividing the annular chamber into a plurality of pump chambers (B); a suction port (62, 121) defined in a first section of the annular chamber in which each of the pump chambers (B) expands with the rotation of the rotor (3); a discharge port (63, 122) defined in a second section of the annular chamber in which each of the pump chambers (B) contracts with the rotation of the rotor (3); a first fluid passage (C1) hydraulically connected to one of the first and second fluid pressure chambers (A1; A2); a second fluid passage (C2) hydraulically connected to one of the suction port and the discharge port (62, 121; 63, 122); and an electromagnetic valve (300) hydraulically connected to the first and second fluid passages (C1, C2) for controlling fluid communication therebetween.

2. The variable displacement vane pump as claimed in claim 1, further comprising:

a discharge passage (OUT) downstream with respect to the discharge port (63, 122), the discharge passage (OUT) including an orifice (8); and a control valve (200) hydraulically connected to upstream and downstream portions of the discharge passage (OUT) with respect to the orifice (8) and hydraulically connected to one of the first and second fluid pressure chambers (A1; A2) for controlling an internal pressure of the one of the first and second fluid pressure chambers (A1; A2).

3. The variable displacement vane pump as claimed in claim 2, wherein:

the second fluid pressure chamber (A2) is hydraulically connected to the suction port (62, 121); the control valve (200) is hydraulically connected to the suction port (62, 121); and the control valve (200) hydraulically connects the first fluid pressure chamber (A1) selectively to one of the suction port and the discharge port (62, 121; 63, 122).

4. The variable displacement vane pump as claimed in claim 2, wherein the control valve (200) hydraulically connects the first fluid pressure chamber (A1) to the upstream portion of the discharge passage (OUT), and hydraulically connects the second fluid pressure chamber (A2) to the downstream portion of the discharge passage (OUT).

5. The variable displacement vane pump as claimed in claim 1, wherein:

the first fluid passage (C1) is hydraulically connected to the first fluid pressure chamber (A1); the second fluid passage (C2') is hydraulically connected to the discharge port (63, 122); and the electromagnetic valve (300) controls fluid communication between the first fluid pressure chamber (A1) and the discharge port (63, 122).

6. The variable displacement vane pump as claimed in claim 4, wherein:

the first fluid passage (C1) is hydraulically connected to the first fluid pressure chamber (A1); the second fluid passage (C2) is hydraulically connected to the suction port (62, 121); and the electromagnetic valve (300) controls fluid communication between the first fluid pressure chamber (A1) and the suction port (62, 121).

7. The variable displacement vane pump as claimed in claim 2, wherein:

the control valve (200) is hydraulically connected to the suction port (62, 121); and the control valve (200) hydraulically connects the second fluid pressure chamber (A2) selectively to one of the suction port and the discharge port (62, 121; 63, 122).

8. The variable displacement vane pump as claimed in claim 7, wherein:

the first fluid passage (C1) is hydraulically connected to the second fluid pressure chamber (A2); the second fluid passage (C2') is hydraulically connected to the discharge port (63, 122); and the electromagnetic valve (300) controls fluid communication between the second fluid pressure chamber (A2) and the discharge port (63, 122).

9. The variable displacement vane pump as claimed in claim 2, further comprising:
a separator (70) mounted in contact with the cam ring (4) within the pump body (10), the separator (70) defining a third fluid pressure chamber (A3) and the second fluid pressure chamber (A2) on both sides thereof, the third fluid pressure chamber (A3) having an internal pressure (P3) acting on the cam ring (4) in a direction to move the cam ring (4) toward the second end position; and a third fluid passage (C3) hydraulically connected to the third fluid pressure chamber (A3), wherein the electromagnetic valve (300) is hydraulically connected to the third fluid passage (C3) for controlling fluid communication through the third fluid passage (C3).

10. The variable displacement vane pump as claimed in claim 1, wherein the first fluid passage (C5) has an opening (C5a) in one of axial end surfaces of the one of the first and second fluid pressure chambers (A1; A2).

11. The variable displacement vane pump as claimed in claim 10, wherein the opening (C5a) of the first fluid passage (C5) is defined in a position such that, when the cam ring (4) is in any position between the first and second end positions, at least part of the opening (C5a) is constantly open to the one of the first and second fluid pressure chambers (A1; A2).

12. The variable displacement vane pump as claimed in claim 1, further comprising a fourth fluid passage (C9) hydraulically connects the electromagnetic valve (300) to the discharge port (63, 122), wherein the one of the suction port and the discharge port (62, 121; 63, 122) is the suction port (62, 121), wherein the electromagnetic valve (300) hydraulically connects the first fluid passage (C7) selectively to one of the second and fourth fluid passages (C8; C9).

13. The variable displacement vane pump as claimed in claim 12, wherein the one of the first and second fluid pressure chambers (A1; A2) is the first fluid pressure chamber (A1).

14. The variable displacement vane pump as claimed in claim 12, wherein the one of the first and second fluid pressure chambers (A1; A2) is the second fluid pressure chamber (A2).

15. The variable displacement vane pump as claimed in claim 12, further comprising:

a separator (70) mounted in contact with the cam ring (4) within the pump body (10), the separator (70) defining a third fluid pressure chamber (A3) and the second fluid pressure chamber (A2) on both sides thereof, the third fluid pressure chamber (A3) having an internal pressure (P3) acting on the cam ring (4) in a direction to move the cam ring (4) toward the second end position; and a third fluid passage (C3) hydraulically connecting the electromagnetic valve (300) to the third fluid pressure chamber (A3), wherein the electromagnetic valve (300) hydraulically connects the third fluid passage (C3) selectively to one of the second and fourth fluid passages (C8; C9).

16. The variable displacement vane pump as claimed in claim 1, wherein the electromagnetic valve (300) includes a valve mechanism (320) disposed between the first and second fluid passages (C1, C2), and an electromagnetic actuator (SOL) for controlling the valve mechanism (320).

17. The variable displacement vane pump as claimed in claim 16, further comprising a suction passage (IN) defined within the pump body (10), and hydraulically connected to the suction port (62, 121) and an outside suction pipe (14), wherein the electromagnetic actuator (SOL) is arranged close to the opening of the suction passage (IN).

18. The variable displacement vane pump as claimed in claim 17, wherein the electromagnetic actuator (SOL) has a longitudinal axis perpendicular to the axis of the rotor (3).

19. The variable displacement vane pump as claimed in claim 16, wherein the valve mechanism (320) of the electromagnetic valve (300) is closed when the electromagnetic actuator (SOL) is subject to a malfunction.

20. The variable displacement vane pump as claimed in claim 19, wherein the valve mechanism (320) of the electromagnetic valve (300) is closed when the electromagnetic actuator (SOL) is de-energized.

21. The variable displacement vane pump as claimed in claim 1, further comprising:

a drive shaft (2) rotatably supported on the pump body (10) and mechanically coupled to the rotor (3) for rotation with the rotation of the rotor (3); a seal (50) disposed radially outside of the cam ring (4), the seal (50) defining the first and second fluid pressure chambers (A1; A2) on both sides thereof; a first member (6) mounted within the pump body (10) and disposed at an axial end of the cam ring (4); and a second member (12) mounted within the pump
22. A variable displacement vane pump comprising:

- a pump body (10); the second end position than when the cam ring (4) is in the first end position;
- a cam ring (4) movably mounted within the pump body (10); a separator (70) mounted in contact with the cam ring (4) within the pump body (10), the separator (70) defining a third fluid pressure chamber (A3) and the second fluid pressure chamber (A2) on both sides thereof, the third fluid pressure chamber (A3) having an internal pressure (P3) acting on the cam ring (4) in a direction to move the cam ring (4) toward the second end position; and a third fluid passage (C3) hydraulically connected to the third fluid pressure chamber (A3); and a first valve (300) hydraulically connected to the third fluid passage (C3) for controlling fluid communication through the third fluid passage (C3).
- a plurality of vanes (32) arranged circumferentially at an outer radial periphery of the rotor (3) extending radially and dividing the annular chamber into a plurality of pump chambers (B); a suction port (62, 121) defined in a first section of the annular chamber in which each of the pump chambers (B) expands with the rotation of the rotor (3); and a fourth fluid passage (C4a) hydraulically connected to the suction port (62, 121); and a fifth fluid passage (25) hydraulically connecting the third fluid pressure chamber (A3) to the discharge port (63, 122), wherein the first valve (300) is hydraulically connected to the second fluid passage (C4) for controlling fluid communication between the second and third fluid passages (C3, C4).
- the suction port (62, 121) and the discharge port (63, 122), wherein the first valve (300) is hydraulically connected to the second fluid pressure chamber (A1) having an internal pressure (P1) acting on the cam ring (4) in a direction to move the cam ring (4) toward the second end position; and a third fluid passage (C3) hydraulically connected to the third fluid pressure chamber (A3); and a first valve (300) hydraulically connected to the third fluid passage (C3) for controlling fluid communication through the third fluid passage (C3).
- a discharge port (63, 122) defined in a second section of the annular chamber in which each of the pump chambers (B) contracts with the rotation of the rotor (3), the discharge port (63, 122) defining a third section of the annular chamber from the suction port (62, 121) to the discharge port (63, 122) along the direction of rotation of the rotor (3), the third section having a larger volumetric capacity when the cam ring (4) is in
- a cam ring (4) movably mounted within the pump body (10), the cam ring (4) and the pump body (10) defining first and second fluid pressure chambers (A1, A2) therebetween, the first fluid pressure chamber (A1) having a volumetric capacity that increases when the cam ring (4) moves toward a first end position, the second fluid pressure chamber (A2) having a volumetric capacity that increases when the cam ring (4) moves toward a second end position; and a rotor (3) mounted inside the cam ring (4) at least for rotation about an axis in a direction, the rotor (3) defining an annular chamber outside thereof; a plurality of vanes (32) arranged circumferentially at an outer radial periphery of the rotor (3) for movement with the rotation of the rotor (3), each of the slots (31) extending radially and accommodating a respective one of the vanes (32) for allowing longitudinal movement thereof; the suction port (62, 121) is defined in one of the first and second members (6, 12); the discharge port (63, 122) is defined in one of the first and second members (6, 12); and a rotor (3) including a plurality of slots (31) arranged circumferentially at the outer radial periphery of the rotor (3), each of the slots (31) extending radially and accommodating a respective one of the vanes (32) for allowing longitudinal movement thereof; the suction port (62, 121) is defined in one of the first and second members (6, 12); the discharge port (63, 122) is defined in one of the first and second members (6, 12); and the electromagnetic valve (300) controls fluid communication between the first fluid pressure chamber (A1) and the discharge port (63, 122) and between the second fluid pressure chamber (A2) and one of the suction port (62, 121) and the discharge port (63, 122).

23. The variable displacement vane pump as claimed in claim 22, further comprising:

- a fluid communication between the third and fourth fluid passages (C3, C4).
122), the method comprising:

adjusting the controlled internal pressure \((P1)\) of the first fluid pressure chamber \((A1)\) in accordance with an operating state of the vehicle by the electromagnetic valve \((300)\).

26. The method as claimed in claim 25, further comprising closing the electromagnetic valve \((300)\) during a failed condition thereof.
REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

• JP 2004218430 A [0002] [0003]  
• JP 2006063851 A [0110] [0110]