

June 14, 1966

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3,255,704

PUMP

Filed Feb. 24, 1965

2 Sheets-Sheet 1

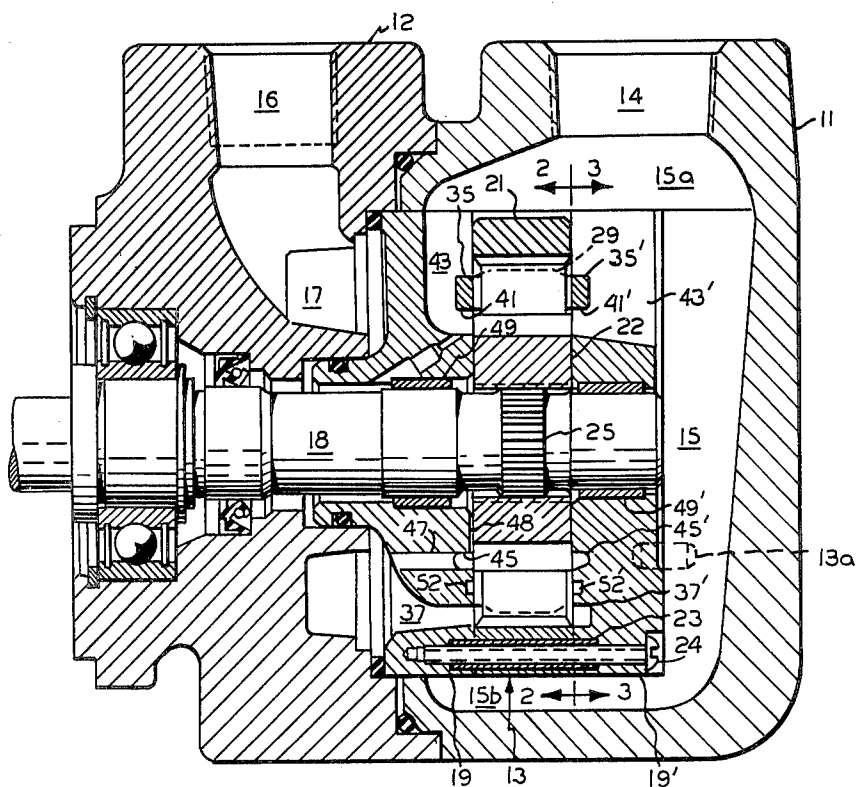


FIG. 1

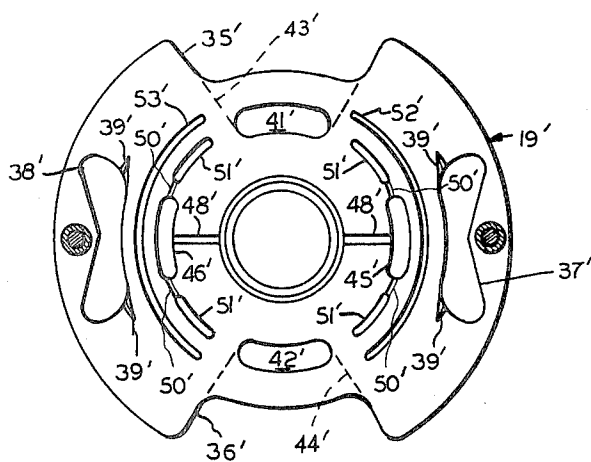


FIG. 3

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2 Sheets-Sheet 2

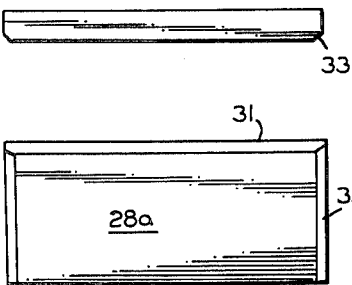
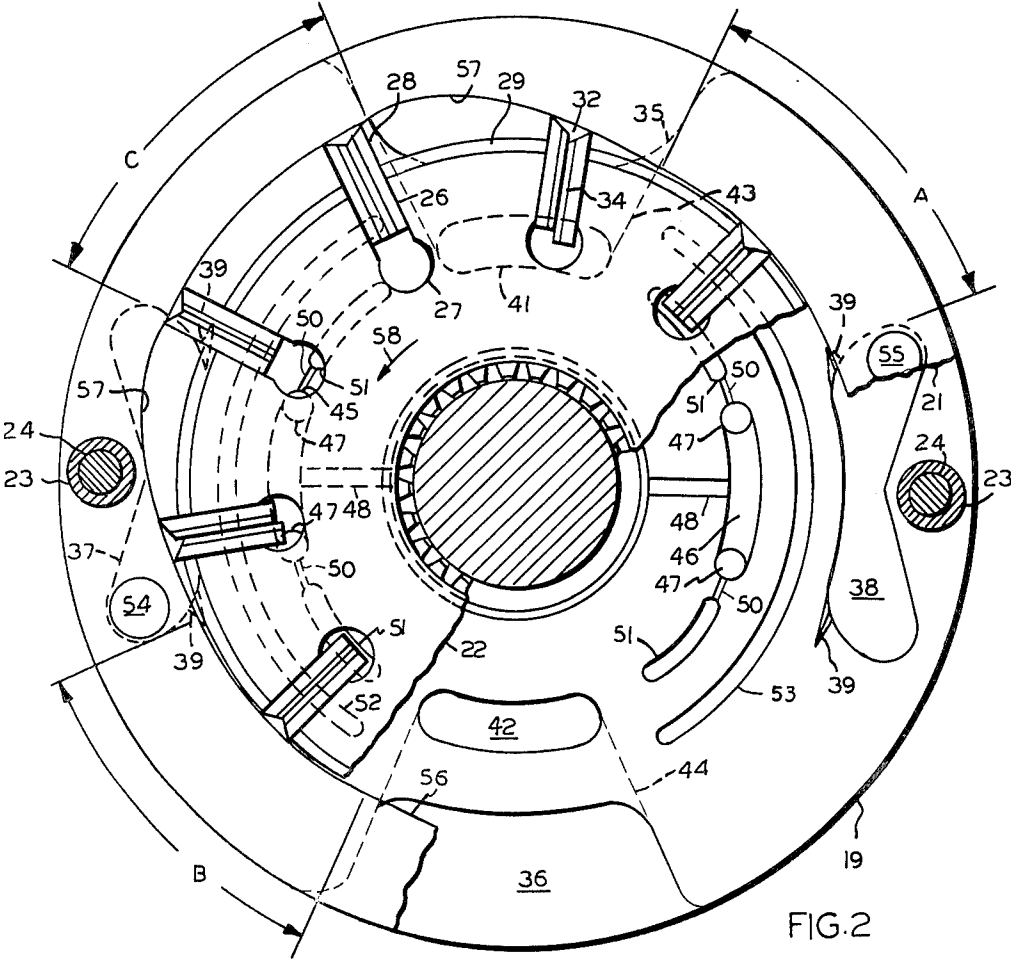


FIG. 4

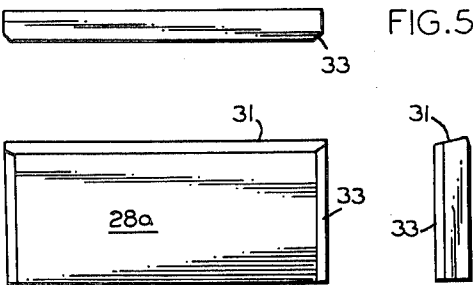


FIG. 5

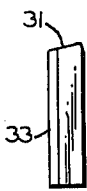


FIG. 6

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Filed Feb. 24, 1965, Ser. No. 434,821
8 Claims. (Cl. 103—136)

This application is a continuation-in-part of my co-pending application, Serial No. 354,573, filed March 25, 1964, now abandoned.

This invention relates to hydraulic pumps of the vane type, and more particularly to vane pumps employing vanes of the dual leaf type described in Rosen Patent 2,393,223, granted January 15, 1946.

In pumps of this type, it is important that the magnitude of the net outward directed force acting on each vane be closely controlled so that an effective seal can be created between the vane and the cam ring without causing undue wear of the cam ring. Commonly, the pressure biasing scheme used for the vane includes a low pressure biasing port which is connected with the inlet port and which registers with the space in each vane slot beneath the vane as the vane passes through the inlet zone, and a high pressure biasing port which is connected with the discharge port and which registers with the inner end of each vane slot after the vane leaves the inlet zone and during its passage to and through the discharge zone. The intent is to substantially balance the pressure forces acting on the outer and inner ends of the vanes when the vanes are in the regions of the inlet and discharge zones and to develop a net outward directed pressure force on each vane as it moves along the constant radius portion of the cam ring located between these zones. In this way, the required seal between each vane and the cam ring is effected as the vane moves from the inlet zone to the discharge zone while minimizing wear in the regions of those zones.

In operation, it sometimes happens that vanes moving through the inlet zone, in which the cam ring is shaped to allow them to move outward, become separated from the cam ring. This condition is attributable, at least in part, to the fact that the outer and side edges of the mating face of each vane leaf are beveled or chamfered to define a balance chamber at the tip of the vane and restricted passages at the sides of the vane which connect this chamber with the base of the vane slot. Since the bevel on the outer end of the trailing leaf is at its leading edge, it develops an oil wedge that urges the leaf inward. If a vane, or a leaf thereof, is spaced from the cam ring as it leaves the inlet zone and the inner end of its vane slot moves into registration with the high pressure biasing port, the vane or the leaf is shot rapidly outward into contact with the cam ring. Repeated impacts of the vanes on the cam ring produce indentations in the ring in the region between the inlet and discharge zones and thus impair the service life of the pump.

The object of this invention is to provide an improved vane pump in which the magnitude of the impacts of separated vanes upon the cam ring is substantially reduced, and which, therefore, has a longer service life. According to the invention, the pump is provided with means for clamping each vane against a side wall of its vane slot as the vane leaves the inlet zone and before the biasing pressure acting beneath it is increased. This clamping action increases the sliding friction of the vane and thus serves to retard its outward acceleration. While this clamping feature, by itself, effects a significant reduction in the severity of vane impacts upon the cam ring, further improvement can be had by incorporating a second feature of the invention. This second feature concerns the provision of an auxiliary biasing port which communicates

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with the inner end of each vane slot after the slot has been disconnected from the low pressure biasing port and the vane has been clamped, but before the slot is connected with the high pressure biasing port, and which receives high pressure fluid through a restricted flow passage leading from a high pressure space in the pump. The restriction afforded by the flow passage limits the rate at which fluid can be supplied to the auxiliary biasing port, and thus tends to limit the speed at which a separated vane or vane leaf can move outward in its vane slot. After contact between the vane and the cam ring has been established, the vane comes to rest and ceases to impose a flow demand on the auxiliary biasing port. Therefore, at this time, the pressure in the auxiliary biasing port rises and the pressure forces developed on the inner and outer ends of the vane hold the vane in sealing engagement with the cam ring.

In its preferred form, the invention is embodied in a double lobe pump and is arranged to be effective in either direction of rotation of the pump. This form of the invention serves not only to reduce the severity of impacts of the vanes on the cam ring in the regions between each inlet zone and the next discharge zone, but also as a convenient means for maintaining the vanes in contact with the cam ring as they move between each discharge zone and the next inlet zone.

In addition to the features mentioned above, the illustrated embodiment of the invention includes a third feature which further reduces the magnitude of the vane impacts on the cam ring. In this embodiment, the clamping means takes the form of pressurized ports formed in the end walls or port plates of the pumping chamber and positioned circumferentially to register with the restricted side passages of each vane after its balance chamber has moved out of communication with the inlet port but before the inner end of its slot overtravels the auxiliary biasing port. As the leading edge of a vane crosses these clamping ports, high pressure oil is introduced into the clearance space between the leading vane leaf and the front wall of the vane slot. This pressurized oil develops a clamping force that urges the two vane leaves against the rear wall of the vane slot, and also serves to lubricate the mating faces of the leading vane leaf and the front wall of the vane slot. When the vane moves to a position in which the restricted side passages register with the clamping ports, these passages are pressurized and oil tends to flow from the clamping ports toward the balance chamber at the tip of the vane. It has been found that when the clamping ports are made to perform this additional function of pressurizing the side passages after the balance chamber has been disconnected from the inlet port and before the vane slot registers with the auxiliary biasing port, the magnitude of the vane impacts on the cam ring is minimized.

The preferred embodiment of the invention is described herein in detail with reference to the accompanying drawings in which

FIG. 1 is an axial sectional view of a double lobe vane pump incorporating the invention, the porting in one discharge zone of each port plate having been rotated into the plane of section.

FIG. 2 is an enlarged sectional view taken on line 2—2 of FIG. 1 with a portion of the rotor and cam ring being broken away to reveal the porting in the face of port plate 19.

FIG. 3 is a face view of port plate 19' taken on line 3—3 of FIG. 1.

FIGS. 4, 5 and 6 are enlarged face, plan and side elevation views, respectively, of one of the vane leaves.

As shown in the drawings, the pump comprises a housing having separable sections 11 and 12 which are joined by bolts (not shown) and which are formed to receive

and hold a pumping cartridge 13. A locating pin 13a orients cartridge 13 with respect to the housing. Housing section 11 contains an inlet port 14 that communicates with an inlet manifold 15 having diametrically opposed, longitudinal extensions 15a and 15b, and section 12 contains a discharge port 16 that communicates with an annular discharge manifold 17 that encircles drive shaft 18.

Cartridge 13 includes a pair of port plates 19 and 19', a cam ring 21 and a rotor 22. The port plates and the cam ring are aligned by a pair of diametrically opposed sleeves 23 and the unit is held together by two bolts 24 which pass through sleeves 23 and are threaded into tapped holes formed in port plate 19. The rotor 22 is connected in driven relation with shaft 18 by splines 25 and is formed with ten uniformly spaced, radial slots 26 whose bases are defined by through cross bores 27 and which receive the sliding vanes 28. The outer peripheral edges of the rotor are beveled at 29 to improve access between the ports in port plates 19 and 19' and the intervane working spaces. The vanes 28 are of the type described in the Rosen patent mentioned above and each includes a pair of identical vane leaves 28a. The inner edge at the outer end of each vane leaf is beveled as shown at 31 in FIGS. 4 and 6 to define, with cam ring 21, a balance chamber 32 at the outer tip of the vane. The sides of the vane leaves are chamfered at 33 to define, with the port plates 19 and 19', a restricted passage 34 at each side of the vane that connects the balance chamber 32 with the base of the vane slot.

Referring to FIGS. 1 and 2, the front face of port plate 19 contains a pair of diametrically opposed inlet ports 35 and 36, and a pair of diametrically opposed discharge ports 37 and 38 which are symmetrical about an axis which is normal to the axis that bisects ports 35 and 36. The inlet ports 35 and 36 open through the outer periphery of the port plate and register with the longitudinal extensions 15a and 15b, respectively, of inlet manifold 15, and the discharge ports 37 and 38 extend through the port plate and communicate with discharge manifold 17. The four ports 35-38 are positioned radially to register with the intervane working spaces. Each of the discharge ports 37 and 38 is provided with a pair of shallow tail ports 39, and since these tail ports constitute extensions of the main ports, it will be understood that further references to the main ports 37 and 38 mean the main ports as extended by their tail ports. The angular spacing between the inlet and discharge ports is such that as the balance chamber 32 of one vane moves out of registration with an inlet port, the central plane of the preceding vane crosses the leading edge of the next discharge port in the direction of rotation.

The front face of port plate 19 also contains four equispaced vane biasing ports positioned radially to register with the cross bores 27, there being two diametrically opposed low pressure biasing ports 41 and 42 which are connected with the inlet ports 35 and 36 by passages 43 and 44, respectively, and two diametrically opposed high pressure biasing ports 45 and 46 each of which is connected with the discharge manifold 17 by a pair of bores 47 that extend through the port plate. Bores 47 constitute flow restrictions so that the pressure which exists in ports 45 and 46 is slightly higher than that in discharge ports 37 and 38. A pair of shallow radial grooves 48 connect biasing ports 45 and 46 with the central opening in port plate 19 and thus provide a restricted path through which oil can be delivered to the shaft bearing 49. Interposed between each of the high pressure biasing ports 45 and 46 and the low pressure biasing ports 41 and 42 is a blind auxiliary biasing port 51 which is positioned radially to register with the cross bores 27. The circumferential spacing between each port 51 and the adjacent low pressure biasing port is slightly greater than the circumferential width of the base of each vane slot, and the spacing between each port 51 and the adjacent high

pressure biasing port is less than the circumferential width of the vane slot base. Positioned radially between the eight vane biasing ports and the outer periphery of rotor 22 are a pair of diametrically opposed, blind clamping ports 52 and 53 which are symmetrical about the axis which bisects discharge ports 37 and 38. The angular extent of ports 52 and 53 is such that one port commences to register with the side passage 34 of a vane leaving the inlet region as the balance chamber 32 of that vane is disconnected from the inlet port, and that its leading edge is tangent to the central plane of a vane, i.e. the mating plane of the two vane leaves, approximately at the same instant the cross bore 27 of the associated vane slot begins to register with an auxiliary biasing port 51. This arrangement minimizes the magnitude of vane impacts on the cam ring. In cases where the ports 52 and 53 are required to perform only a clamping function, their angular extent can be reduced so that the front wall of a vane slot 26 crosses their leading edges slightly in advance of registration of the cross bore 27 with an auxiliary biasing port 51.

The ports in the front face of port plate 19' (see FIG. 3) are identical to those in port plate 19, so corresponding ports bear the same reference numerals with primes added for clarity. However, it should be noted that the discharge ports 37' and 38' and the high pressure biasing ports 45' and 46' in port plate 19' are blind. Fluid pumped into the discharge ports 37' and 38' is delivered to the corresponding ports in port plate 19 through bores 54 and 55, respectively, extending through cam plate 21, and thus is delivered to the discharge manifold 17 along with the fluid pumped directly into the discharge ports 37 and 38. The inlet ports 35' and 36' open through the outer periphery of port plate 19' and communicate, respectively, with manifold extensions 15a and 15b, and are connected with the low pressure biasing ports 41' and 42' by milled passages 43' and 44' which, unlike the corresponding passages 43 and 44 in port plate 19, open through the rear face of the port plate.

The cam surface 56 of cam ring 21 comprises two diametrically opposed circular arcs A and B of equal radius, two additional diametrically opposed circular arcs (one being indicated at C in FIG. 2) of equal radius which are symmetrical about an axis normal to the axis that bisects arcs A and B, and four blend curves or ramps 57 that join the adjacent ends of the four arcs. All four arcs have the same angular extent and all are centered on the axis of rotation. However, as will be evident from FIG. 2, the radius of arcs A and B is smaller than the radius of the remaining two arcs. When the cam ring 21 is installed as illustrated, rotor 22 is driven in the direction of arrow 58 in FIG. 2 so that the fluid which enters the intervane spaces at inlet ports 35, 35' and 36, 36' discharges through ports 37, 37' and 38, 38', respectively. The direction of rotation of the pump can be reversed by turning over the cam ring 21 so that, in effect, the major axis, i.e., the axis which bisects arc C, is rotated 90° in the clockwise direction as viewed in FIG. 2. In the reverse mode of operation, fluid is pumped from inlet ports 35 and 35' to discharge ports 38 and 38' and from inlet ports 36 and 36' to discharge ports 37 and 37'. Since the direction of rotation of the illustrated pump may be changed, this embodiment includes an auxiliary biasing port 51, 51' at each side of each inlet port and a clamping port 52, 52' or 53, 53' that extends from each discharge zone toward each inlet zone. Although the biasing ports 51, 51' and those portions of clamping ports 52, 52', and 53, 53' lying within the general region of true arcs A and B are not required to retard outward motion of separated vane leaves when the pump is rotating in the direction of arrow 58, as explained below these parts do serve as a convenient means of maintaining the vanes in contact with the cam ring in the regions of arcs A and B.

Although the illustrated pump is of the double lobe

type, and thus affords two pumping cycles per revolution of rotor 22, the description of operation will be confined to only one cycle, namely the one involving inlet ports 35 and 35' and discharge ports 37 and 37'. As the rotor 22 rotates in the direction of the arrow 58 in FIG. 2, the vanes 28 in the inlet region move outward along the ramp 57 between arcs A and C and thus increase the volume of the intervane working space between each adjacent pair of vanes. As a result, fluid in inlet port 14 is drawn into the working spaces through manifold 15, extension 15a and the ports 35 and 35'. As the vanes move onto and across arc C, the intervane space is first disconnected from the inlet ports 35 and 35' and then connected with the discharge ports 37 and 37'. When the vanes defining the boundaries of a working space pass onto the ramp 57 between arcs C and B, they commence to move inward and decrease the volume of this space. As a result, fluid is displaced from the intervane working space and delivered to a discharge port 16 through port 37 and manifold 17 and through port 37', bore 54, and port 37.

As a vane 28 travels through the inlet zone, the cross bore 27 at the base of its vane slot registers with the low pressure biasing ports 41 and 41', and, therefore, the entire cross sectional area of both the inner and outer ends of the vane are subjected to essentially the same low pressure. Thus, in this portion of the pumping cycle, the vanes 28 are held against the cam ring primarily by centrifugal force. When the vane 28 nears the end of the inlet port 35 and moves onto the arc C, the leading edge of its vane slot 26 crosses the leading ends of clamping ports 52 and 52'. This permits the fluid in the clamping ports to flow into the clearance space between the leading leaf 28a and the leading wall of the vane slot 26 where it develops a force that urges the vane against the trailing wall of the vane slot. Fluid is transmitted to the clamping ports 52 and 52' from the discharge ports 37 and 37' through the restricted passages 34 in the sides of those vanes 28 which are in the discharge zone, and, therefore, the clamping force developed on the vane 28 leaving the inlet zone is sufficient to materially increase its sliding friction. In addition, the pressurized oil in the clearance space between the vane and the front wall of its slot insures full lubrication of the mating surface of these elements.

After the vane is clamped, its balance chamber 32 is disconnected from the inlet ports 35 and 35', and its side passages 34 commence to register with clamping ports 52 and 52'. The pressure in these side passages now increases and oil tends to flow radially outward toward the balance chamber 32 at the tip of the vane. As the restricted passages 34 move across ports 52 and 52', the cross bore 27 moves out of registration with the biasing ports 41 and 41' and, when the mating plane of the vane leaves crosses the leading edges of the ports 52 and 52', the cross bore 27 commences to register with the auxiliary biasing ports 51 and 51'. At this time, the cross bore 27 associated with the next preceding vane 28 in the direction of rotation is spanning ports 45 and 45' on the one hand, and ports 51 and 51' on the other hand, so fluid from the high pressure biasing ports 45 and 45' may flow into the auxiliary biasing ports 51 and 51', respectively. If a leaf 28a of the vane 28 which has just left the inlet zone is separated from the cam surface 56, the pressure in ports 51 and 51' will move it outward into contact with the cam ring. However, three features of the present pump cooperate to retard this movement, and thus minimize the magnitude of the impact of the vane leaf on the cam ring. First, the vane is clamped so that its sliding friction is increased. Second, the balance chamber 32 is isolated from the inlet ports and the restricted side passages 34 are pressurized before cross bore 27 begins to register with ports 51 and 51'. It is thought that this feature causes the pressure in the bal-

ance chamber 32 to rise simultaneously with the pressure acting beneath the vane and to develop on the outer end of the vane leaf an inward directed force that resists outward movement. Third, the restricted flow path defined by the cross bore 27 of the next preceding vane limits the rate at which oil can be supplied to ports 51 and 51' and to the space in the vane slot beneath the separated vane. When the separated leaf contacts the cam ring it comes to rest and ceases to impose a flow demand on ports 51 and 51'. As a result, the pressure in these ports rises to the value prevailing in high pressure biasing ports 45 and 45'. At this time the pressures acting on the inner and outer ends of the vane develop a net force which, in conjunction with the centrifugal force, maintains the vane in sealing engagement with the cam ring.

When a vane 28 is moved into a position in which the trailing edge of its slot crosses ports 52 and 52', the clamping force is neutralized and the vane is freed, and the cross bore 27 of the next preceding vane moves out of registration with auxiliary biasing ports 51 and 51'. Since the ports 51 and 51' still are in communication with the high pressure biasing ports 45 and 45' through the restricted passages 34 at the sides of the vane 28 traveling along arc C, the clamping ports 52 and 52', and the restricted passages 34 at the opposite sides of the preceding vane 28 in the discharge zone, high pressure is maintained in the auxiliary biasing ports. Therefore, the vane 28 moving toward the discharge zone remains in sealing engagement with the cam ring. As this vane breaks into the discharge zone, the associated cross bore 27 registers with high pressure biasing ports 45 and 45', so the pressure forces acting on its inner and outer ends are nearly, but not completely, balanced. Thus, as this vane passes through the discharge zone, it is kept in contact with the cam ring by a small outward directed pressure force and by centrifugal force.

It should be noted that as a vane 28 moves across arc B, the trailing intervane working space is in communication with the discharge zone defined by ports 37 and 37' and thus is subjected to discharge pressure. In the absence of some means to hold the vane 28 against the cam ring, this high pressure could move the vane rapidly inward into contact with the bottom of the vane slot. Repeated impacts of this type might crack the rotor. In the illustrated embodiment, the means for preventing this inward movement of the vanes includes the auxiliary ports 51 and 51' located between the high pressure biasing ports 45 and 45' and the low pressure biasing ports 42 and 42', and those portions of clamping ports 52 and 52' in the region of arc B. These ports 51 and 51', which register with the cross bore 27 associated with the vane traveling along arc B, are connected with the high pressure biasing ports 45 and 45' by the restricted passages 34 at the sides of this vane, the clamping ports 52 and 52' and the restricted passages 34 at opposite sides of the next succeeding vane 28, and thus contain fluid at substantially the same pressure as that prevailing in the high pressure biasing ports 45 and 45'. As a result, the vane crossing arc B is subjected to a net outward directed biasing force which maintains it in sealing engagement with the cam ring. When this vane moves onto the ramp 57 in the region of inlet ports 36 and 36', the associated cross bore 27 is disconnected from auxiliary ports 51 and 51' and connected with low pressure biasing ports 42 and 42'. However, since the outer end of the vane is now subjected to inlet pressure, there is no tendency for the vane to be shot inward.

It has been observed that conventional vane pumps frequently become noisy when they are operated at high speeds, i.e., at speeds above about 2000 r.p.m. It is believed that this condition is attributable, at least in part, to incomplete filling of the vane slots as their cross bores 27 travel across the low pressure biasing ports 41 and 41'. This encourages the formation of air or vapor bubbles in the vane slots. When the vanes subsequently

move into the discharge zone, and the bases of their slots are subjected to high pressure, the bubbles suddenly collapse and sound waves are produced. In the illustrated embodiment, the clamping ports 52 and 52' serve to counteract this condition because some of the oil they deliver to the side passages 34 of each vane can flow into and fill the inner end of the vane slot before the cross bore 27 registers with the auxiliary biasing ports 51 and 51' and is subjected to a high pressure.

It was mentioned above that the auxiliary biasing ports 51 and 51' are supplied with oil from the high pressure biasing ports 45 and 45' through a restricted path defined by the cross bore 27 of one of the vane slots. While this method of feeding oil to the ports 51 and 51' is satisfactory at moderate and high operating speeds, it has been found that, at speeds below about 1200 r.p.m., the rate of supply is so low that contact between the separated vane leaves and the cam ring is not always re-established before the cross bore 27 registers with the high pressure biasing ports 45 and 45'. In cases, such as the engine-driven pumps used on earth-moving vehicles, where the pump must operate frequently at low speed, an additional restricted supply path is provided. As shown in FIGS. 2 and 3, this additional path is defined by narrow, shallow grooves 50 and 50' which are formed in the faces of the port plates and which connect each auxiliary biasing port 51 or 51' with the adjacent high pressure ports 45, 46, 45' or 46'.

As stated previously, the drawings and description relate only to the preferred embodiment of the invention. Since changes can be made in the structure of this embodiment without departing from the inventive concept, the following claims should provide the sole measure of the scope of the invention.

What I claim is:

1. In a vane pump including a rotor formed with a plurality of circumferentially spaced vane slots that contain sliding vanes of the dual leaf type; a cam ring encircling the rotor and shaped to allow the vanes to move outward during a first portion of a revolution of the rotor, to move the vanes inward during a second portion of a revolution, and to allow the vanes to assume a radially stable position during a third portion of a revolution intermediate the first and second portions; circumferentially spaced inlet and discharge ports communicating with the intervane working spaces as the vanes move outward and inward, respectively; means for subjecting the inner ends of the vanes to a low pressure during said first portion of a revolution; and means for subjecting the inner ends of the vanes to an elevated pressure during said second and third portions of a revolution; the improvement which comprises means for clamping each vane against a wall of its vane slot as it leaves the region of the inlet port and before its inner end is subjected to an elevated pressure.

2. An improved vane pump as defined in claim 1 including the further improvement which consists in that the means for subjecting the inner ends of the vanes to an elevated pressure comprises

- (a) a high pressure biasing port connected with a high pressure space of the pump and arranged to communicate with the space in each vane slot beneath the vane during said second portion of a revolution; and
- (b) an auxiliary biasing port in restricted communication with a high pressure space of the pump and arranged to communicate with the space in each vane slot beneath the vane after the clamping means has been rendered effective to clamp the vane and during said third portion of a revolution.

3. In a vane pump including a rotor formed with a plurality of circumferentially spaced vane slots that contain sliding vanes of the dual leaf type; a cam ring encircling the rotor and shaped to allow the vanes to move outward during a first portion of a revolution of the rotor, to move the vanes inward during a second portion of a revolution,

and to allow the vanes to assume a radially stable position during a third portion of a revolution intermediate the first and second portions; a pair of transverse end walls adjacent opposite sides of the rotor; circumferentially spaced inlet and discharge ports registering with the intervane working spaces as the vanes move outward and inward, respectively; a low pressure biasing port located in a transverse end wall and registering with the spaces in the vane slots beneath the vanes during said first portion of a revolution; and high pressure biasing port means located in a transverse end wall and registering with the spaces in the vane slots beneath the vanes during said second and third portions of a revolution; the improvement which comprises

- (a) a clamping port located in a transverse end wall and positioned radially intermediate the outer periphery of the rotor and the inner ends of the vanes when the vanes are fully extended, the leading end of the clamping port being positioned circumferentially to register with each vane slot as the associated vane leaves the region of the inlet port and before its inner end registers with the high pressure biasing port means; and

- (b) passage means connecting the clamping port with the discharge port.

4. An improved vane pump as defined in claim 3 including the further improvement which consists in that the high pressure biasing port means comprises

- (a) a high pressure biasing port located in a transverse end wall and connected with a high pressure space of the pump, this port being arranged to register with the space in each vane slot beneath the vane when the vane is moving inward;

- (b) an auxiliary biasing port located in a transverse end wall and positioned circumferentially between the low and high pressure biasing ports and positioned radially to register with the spaces in the vane slots beneath the vanes, the leading end of the auxiliary biasing port being spaced circumferentially from the trailing end of the low pressure biasing port a distance not less than the width of a vane slot and so located that it registers with a vane slot after the leading edge but before the trailing edge of that slot crosses the clamping port, and the trailing end of the auxiliary biasing port being spaced from the leading end of the high pressure biasing port a distance less than the width of a vane slot,

- (c) the length of the auxiliary biasing port being so correlated with the intervane spacing that one vane slot spans the auxiliary and high pressure biasing ports as the next succeeding vane slot commences to register with the auxiliary biasing port; and

- (d) restricted passage means associated with each vane and connecting the space in each vane slot beneath the vane with the clamping port when the vane overlies that port.

5. In a vane pump including a pumping chamber defined by a cam ring and a pair of transverse end walls, a rotor located in the chamber and containing a plurality of circumferentially spaced vane slots, a vane comprising two leaves reciprocable in each slot, bevels at the outer ends of the vane leaves defining with the cam ring a balance chamber at the outer end of each vane, chamfers on the opposite edges of the mating faces of the leaves of each vane defining with the transverse end walls a restricted passage at each side of the vane that connects the balance chamber with the space in the vane slot beneath the vane, an inlet port formed in a transverse end wall and positioned radially to register with the intervane spaces, a discharge port formed in a transverse end wall and positioned radially to register with the intervane spaces and spaced circumferentially from the inlet port, a low pressure biasing port formed in a transverse end wall and connected with the inlet port and positioned radially to register with the space in each vane slot beneath the vane when the

vane is in the region of the inlet port, and a high pressure biasing port formed in a transverse end wall and connected with the discharge port and positioned radially to register with the space in each vane slot beneath the vane as the vane moves through the region of the discharge port, the improvement which comprises

- (a) a clamping port located in a transverse end wall and positioned radially intermediate the outer periphery of the rotor and the inner ends of the vanes when the vanes are fully extended, the clamping port being so positioned circumferentially that it commences to register with a restricted side passage of a vane as the balance chamber of the vane is disconnected from the inlet port; and
- (b) an auxiliary biasing port located in a transverse end wall and positioned circumferentially between the low and high pressure biasing ports and positioned radially to register with the spaces in the vane slots beneath the vanes, the leading end of the auxiliary biasing port being positioned circumferentially to register with a vane slot after the vane slot has moved out of registration with the low pressure biasing port and as the mating plane of the two leaves of the associated vane crosses the leading end of the clamping port, and the trailing end of the auxiliary biasing port being spaced circumferentially from the leading end of the high pressure biasing port a distance less than the width of a vane slot,
- (c) the intervane spacing being so chosen that one vane slot spans the auxiliary and high pressure biasing ports as the next succeeding vane slot commences to register with the auxiliary biasing port.

6. An improved vane pump as defined in claim 5 including the further improvement which comprises a groove located in a transverse end wall and defining with the rotor a restricted passage interconnecting the auxiliary and high pressure biasing ports.

7. In a vane pump including a pumping chamber containing a rotor formed with a plurality of circumferentially spaced vane slots; a vane comprising two leaves reciprocable in each vane slot; transverse end wall means closing opposite ends of the pumping chamber and containing a pair of diametrically opposed inlet ports and a pair of diametrically opposed discharge ports; a cam ring encircling the rotor and provided with a ramp in the region of each inlet port which allows outward movement of the vanes, a ramp in the region of each discharge port which serves to move the vanes inward, a true arc of major radius between each inlet region and the adjacent discharge region in the direction of rotor rotation, and a true arc of minor radius between each discharge region and the adjacent inlet region in the direction of rotor rotation; bevels at the outer ends of the vane leaves defining with the cam ring a balance chamber at the outer end of each vane; chamfers on the opposite edges of the mating faces of the leaves of each vane defining with the transverse end wall means a restricted passage at each side of the vane that connects the balance chamber with the space in the vane slot beneath the vane; a low pressure biasing port formed in the end wall means in the region of each inlet port, the low pressure biasing ports being connected with the low pressure ports and being positioned

radially to register with the spaces in the vane slots beneath the vanes; and a high pressure biasing port formed in the transverse end wall means in the region of each discharge port, the high pressure biasing ports being connected with the discharge ports and positioned radially to register with the spaces in the vane slots beneath the vanes; the improvement which comprises

- (a) two diametrically opposed identical clamping ports formed in the transverse end wall means and positioned radially intermediate the outer periphery of the rotor and the inner ends of the vanes when the vanes are fully extended, the parts of the pump being so dimensioned and arranged that

- (1) the leading end of each clamping port commences to register with a restricted side passage of each vane as the associated balance chamber is disconnected from an inlet port, and is crossed by the mating plane of the two leaves of the vane as the associated vane slot is disconnected from a low pressure biasing port, and that

- (2) the trailing end of each clamping port is crossed by said mating plane of each vane as the associated vane slot commences to register with a low pressure biasing port, and is disconnected from a restricted side passage of the vane as the associated balance chamber commences to register with an inlet port; and

- (b) four identical auxiliary biasing ports formed in the transverse end wall means and positioned radially to register with the spaces in the vane slots beneath the vanes, one auxiliary biasing port being located circumferentially between a low pressure and a high pressure biasing port, one end of each auxiliary biasing port being spaced from the adjacent end of a low pressure biasing port a distance equal to the width of a vane slot and the other end of each auxiliary biasing port being spaced from the adjacent end of a high pressure biasing port a distance less than the width of a vane slot,

- (c) the length of each auxiliary biasing port being so correlated with the intervane spacing that one vane slot commences to register with an auxiliary biasing port while the preceding vane slot in the direction of rotor rotation spans this auxiliary port and a high pressure biasing port.

8. An improved vane pump as defined in claim 7 including the further improvement which comprises four grooves formed in the transverse end wall means and defining with the rotor four restricted passages, two of said passages connecting one high pressure biasing port with the adjacent auxiliary biasing ports, and the remaining passages connecting the other high pressure biasing port with the adjacent auxiliary biasing ports.

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