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(54) **HYDRAULIC UNIT HAVING ORIFICE PLATE DISPLACEMENT CONTROL**

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(57) **ABSTRACT**

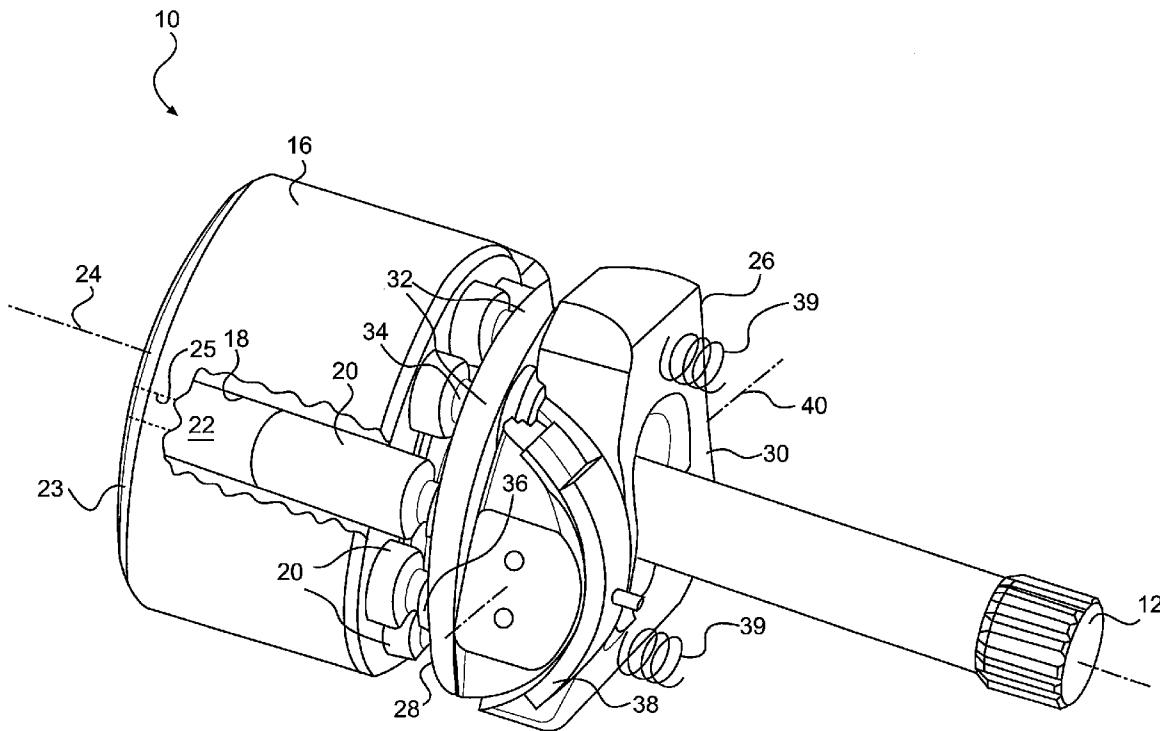
A hydraulic unit is disclosed. The hydraulic unit may have a rotatable body at least partially defining a plurality of barrels, a plurality of plungers associated with the plurality of barrels, and a swashplate tiltable to vary a displacement of the plurality of plungers relative to the plurality of barrels. The hydraulic unit may also have an orifice plate located adjacent the rotatable body. The orifice plate may include an inlet port, a discharge port, and a first plurality of control orifices located between first ends of the inlet and discharge ports. The hydraulic unit may further have a first plurality of control valves, each of the first plurality of control valves being associated with a different control orifice of the first plurality of control orifices.

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Related U.S. Application Data

(60) Provisional application No. 61/193,707, filed on Dec. 17, 2008.



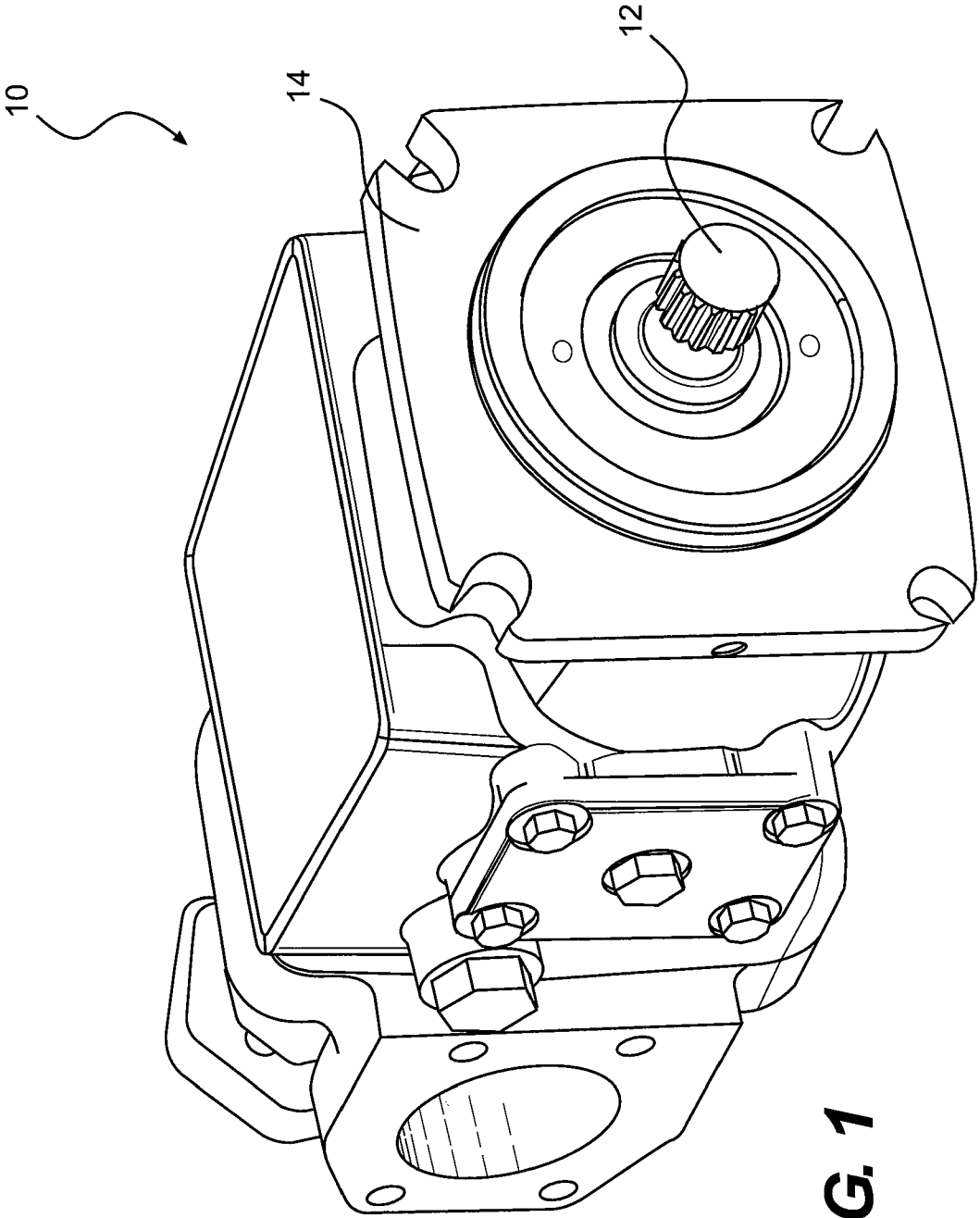


FIG. 1

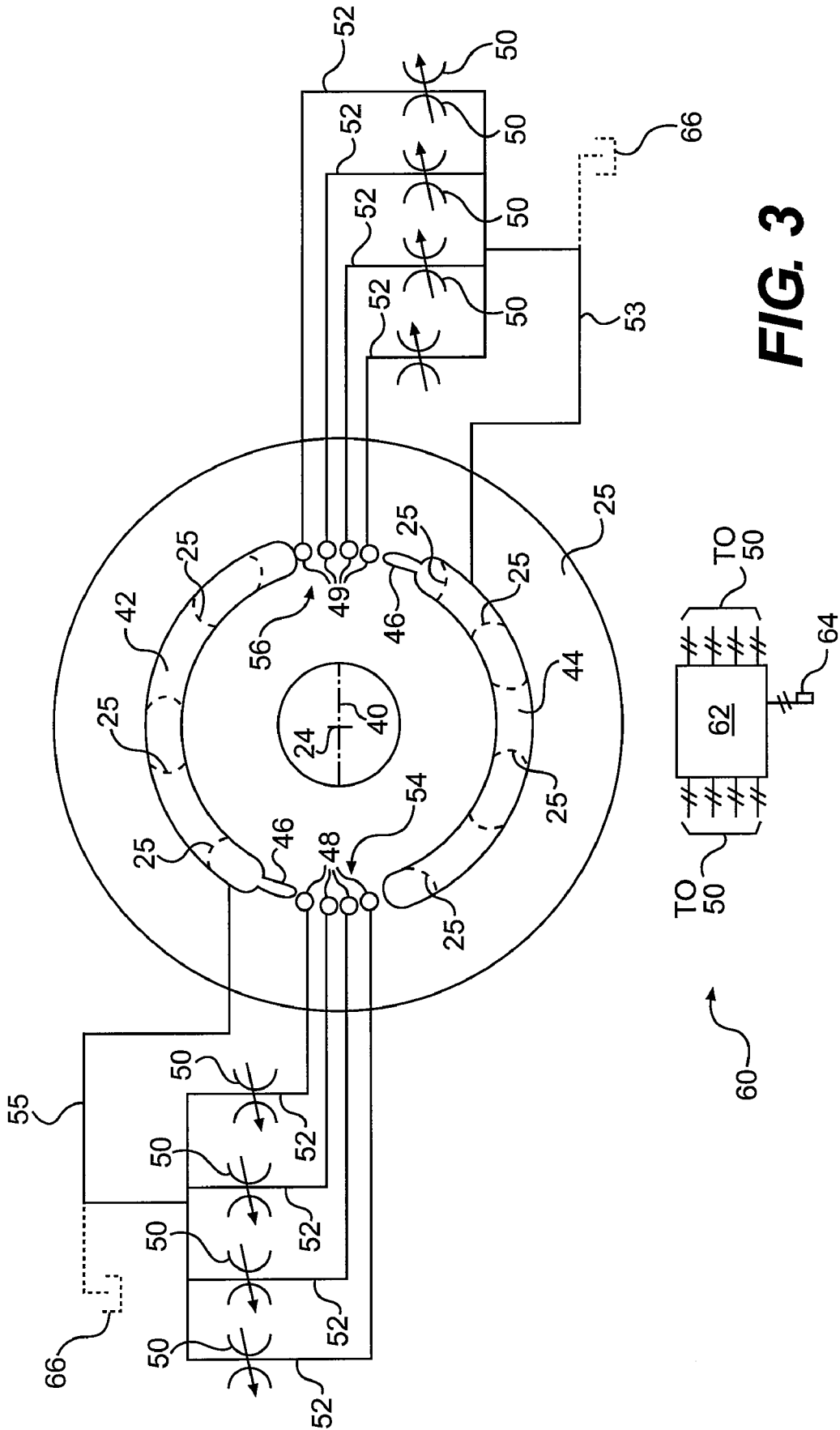


FIG. 3

HYDRAULIC UNIT HAVING ORIFICE PLATE DISPLACEMENT CONTROL

RELATED APPLICATIONS

[0001] This application is based on and claims the benefit of priority from U.S. Provisional Application No. 61/193,707 by Viral S. Mehta and Bryan E. Nelson, filed Dec. 17, 2008, the contents of which are expressly incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure relates generally to a hydraulic unit and, more particularly, to a hydraulic unit having orifice plate displacement control.

BACKGROUND

[0003] Hydraulic tool systems typically employ multiple actuators provided with high pressure fluid from a common pump. In order to efficiently accommodate the different flow and/or pressure requirements of the individual actuators, these systems generally include a pump having variable displacement. Based on individual and/or combined flow and pressure requirements, the pump changes a fluid displacement amount to meet demands. When demand is low, the displacement is reduced to conserve energy.

[0004] Typical variable displacement pumps used in hydraulic tool systems are known as swashplate-type pumps. This type of pump includes a plurality of plungers held against a plunger engagement surface of a tiltable swashplate. A joint such as a ball and socket joint is disposed between each plunger and the engagement surface to allow for relative movement between the swashplate and the plungers. Each plunger is slidably disposed to reciprocate within an associated barrel as the plungers rotate relative to the tilted surface of the swashplate. As each plunger is retracted from the associated barrel, low pressure fluid is drawn into that barrel. When the plunger is forced back into the barrel by the plunger engagement surface of the swashplate, the plunger pushes the fluid from the barrel at an elevated pressure.

[0005] The tilt angle of the swashplate is directly related to an amount of fluid pushed from each barrel during a single relative rotation between the plungers and the swashplate. And, based on a restriction of the pump and/or a fluid circuit connected to the pump, the amount of fluid pushed from the barrel during each rotation is directly related to the flow rate and pressure of fluid exiting the pump. Thus, a higher tilt angle equates to a greater flow rate and/or pressure, while a lower tilt angle results in a lower flow rate and/or pressure. Similarly, a higher tilt angle requires more power from a driving source to produce the higher flow rates and pressures than does a lower tilt angle. As such, when the demand for fluid is low, the swashplate angle is typically reduced to lower the power consumption of the pump.

[0006] Historically, the tilt angle of the swashplate has been controlled by way of a dedicated actuator. That is, an actuator located on one side of the swashplate is selectively extended against a bottom surface of the swashplate or retracted from the swashplate to directly tilt the swashplate about a pivot axis toward a desired angle against a spring bias. Although effective, this additional actuator can be expensive, difficult to control, and slow to respond.

[0007] An exemplary swashplate-type pump having improved tilt angle control is disclosed in U.S. Pat. No. 5,554,

007 (the '007 patent) issued to Watts et al. on Sep. 10, 1996. In the pump design of the '007 patent, a head assembly is disposed on an opposing end of a plurality of plungers from a tiltable swashplate. The head assembly has arcuately shaped low- and high-pressure passages, and a pair of control pockets defined therein. The control pockets are disposed on opposing sides of the head assembly, between ends of the low- and high-pressure passages, in regions commonly referred to as top- and bottom-dead-centers. The plungers are sequentially communicated with the low-pressure passage, a first control pocket, the high-pressure passage, and a second control pocket, as the plungers are rotated relative to the swashplate. A spring resiliently biases the swashplate toward a minimum displacement position. A control valve is disposed between the first control pocket and the low-pressure passage to control fluid flow from the control pocket to the low-pressure passage. Similarly, another control valve is disposed between the high-pressure passage and the second control pocket to control fluid flow from the high-pressure passage to the second control pocket. A controller selectively operates the control valves to affect a torque placed on the swashplate by the plungers so as to control the tilt angle of the swashplate. In this manner, a dedicated tilt actuator is not required.

[0008] While the pump of the '007 patent may provide for swashplate tilt angle modulation without the use of a dedicated actuator, the benefit thereof may be limited. In particular, the pump of the '007 patent may lack fine control required to precisely adjust swashplate tilt angles. Without fine control, efficiency, response, and noise abatement of the pump may be less than desired.

[0009] The disclosed pump is directed to overcoming one or more of the problems set forth above.

SUMMARY OF THE INVENTION

[0010] In one aspect, the present disclosure is directed to a hydraulic unit. The hydraulic unit may include a rotatable body at least partially defining a plurality of barrels, a plurality of plungers associated with the plurality of barrels, and a swashplate tiltable to vary a displacement of the plurality of plungers relative to the plurality of barrels. The hydraulic unit may also include an orifice plate located adjacent the rotatable body. The orifice plate may have an inlet port, a discharge port, and a first plurality of control orifices located between first ends of the inlet and discharge ports. The hydraulic unit may further include a first plurality of control valves, each of the first plurality of control valves being associated with a different control orifice of the first plurality of control orifices.

[0011] In another aspect, the present disclosure is directed to a method of pressurizing fluid. The method may include rotating a plurality of plungers past an inlet port during a retraction stroke of the plurality of plungers to draw in fluid, and rotating the plurality of plungers past a discharge port during an extension stroke of the plurality of plungers to expel fluid. The method may also include selectively changing a force on the plurality of plungers at multiple locations near an end-of-stroke motion of the plurality of plungers to affect a displacement of the plurality of plungers.

[0012] In yet another aspect, the present disclosure is directed to a method of converting power. The method may include directing pressurized fluid into a plurality of pumping chambers as the plurality of pumping chambers rotate past an inlet port, expanding the pressurized fluid within the plurality of pumping chambers to generate a mechanical output, and

discharging the pressurized fluid from the plurality of pumping chambers as the plurality of pumping chambers rotate past a discharge port. The method may also include selectively changing a pressure of the plurality of pumping chambers at multiple locations between first ends of the inlet and discharge ports to affect the mechanical output.

BRIEF DESCRIPTION OF THE DRAWINGS

- [0013] FIG. 1 is a diagrammatic illustration of an exemplary disclosed hydraulic unit;
 [0014] FIG. 2 is a cut-away view of the hydraulic unit of FIG. 1; and
 [0015] FIG. 3 is a diagrammatic illustration of an exemplary disclosed orifice plate that may be used in conjunction with the hydraulic unit of FIG. 1.

DETAILED DESCRIPTION

[0016] FIG. 1 illustrates a hydraulic unit 10, for example a pump or a motor. In one embodiment, hydraulic unit 10 may be driven by an external source of power (not shown), such as a combustion engine, via a driveshaft 12. In another embodiment, hydraulic unit 10 may drive an external device via driveshaft 12. As such, driveshaft 12 may extend from one end of a housing 14 for engagement with the engine or external device.

[0017] As illustrated in FIG. 2, housing 14 may enclose a body 16 at least partially defining a plurality of barrels 18 (only one shown). Hydraulic unit 10 may also include a plurality of plungers 20, one plunger 20 slidingly disposed within each barrel 18. Each barrel 18 and each associated plunger 20 may, together, at least partially define a pumping chamber 22 configured to receive and discharge fluid by way of an orifice plate 23. It is contemplated that any number of pumping chambers 22 may be included within body 16 and symmetrically and radially disposed about a central axis 24. Although central axis 24 is shown as being generally coaxial with driveshaft 12, it is contemplated that central axis 24 may alternatively be oriented at an angle relative to driveshaft 12 such as in a bent-axis type pump or motor, if desired.

[0018] Body 16 may be connected to rotate with driveshaft 12. That is, as driveshaft 12 is rotated by the engine or by fluid pressure, body 16 and plungers 20 located within barrels 18 of body 16 may all rotate together about central axis 24. As body 16 rotates, individual passageways 25 associated with each pumping chamber 22 may pass by inlet and discharge ports of orifice plate 23 to draw in and expel pressurized fluid.

[0019] Hydraulic unit 10 may be a swashplate-type of pump or motor. Specifically, hydraulic unit 10 may include a generally stationary swashplate 26 having a plunger engagement surface 28 and a tiltable base 30. Plunger engagement surface 28 may be located between plungers 20 and tiltable base 30 to operatively engage plungers 20 by way of a joint 32 such as a ball and socket joint. That is, each plunger 20 may have a generally spherical end 34, which may be biased into engagement with a cup-like socket located within a slipper foot. Slipper feet 36 may be configured to slide along plunger engagement surface 28, which may be connected to or otherwise integral with tiltable base 30.

[0020] Swashplate 26 may be tilted to vary a displacement or an expansion amount of plungers 20 relative to barrels 18. Specifically, tiltable base 30 may be situated within a bearing member 38 and pivotal about a tilt axis 40 against the bias of one or more resilient members 39. In one embodiment, tilt

axis 40 may pass through and be substantially perpendicular to central axis 24. As tiltable base 30 and connected plunger engagement surface 28 pivot about tilt axis 40, the plungers 20 located on one half of plunger engagement surface 28 (relative to tilt axis 40) may retract into their associated barrels 18, while the plungers 20 located on an opposing half of plunger engagement surface 28 may extend out of their associated barrels 18 by about the same amount. As plungers 20 rotate about central axis 24, plungers 20 may annularly move from the retracted side of plunger engagement surface 28 to the extended side, and repeat this cycle as driveshaft 12 continues to rotate.

[0021] As plungers 20 retract out of barrels 18, fluid may be drawn into barrels 18. Conversely, as plungers 20 extend into barrels 18, the fluid may be expelled from barrels 18. An amount of movement between the retracted position and the extended position may relate to an amount of fluid displaced or consumed by plungers 20 during a single rotation of driveshaft 12. Because of the connection between plungers 20 and plunger engagement surface 28, the tilt angle of plunger engagement surface 28 (i.e., the angle relative to a perpendicular of central axis 24 that results in positive displacement or expansion of plungers 20) may relate to the movement between the retracted position and the extended position. One or more pressure relief valves (not shown) located within hydraulic unit 10 or within a hydraulic circuit (not shown) supplied with fluid from or supplying fluid to hydraulic unit 10, may affect the pressure of the fluid within pumping chambers 22.

[0022] As shown in FIG. 3, orifice plate 23 may include a generally arcuate inlet port 42 and a similar generally arcuate discharge port 44. At a leading end of each of inlet and discharge ports 42, 44, may be provided a metering slot 46. As body 16 and associated pumping chambers 22 rotate relative to orifice plate 23, passageways 25 may move into and out of fluid communication with inlet and discharge ports 42, 44. Metering slots 46 may help to reduce a shock loading associated with these periodic communications.

[0023] Orifice plate 23 may also include a first plurality of control orifices 48 located between first ends of inlet and discharge ports 42, 44, a second plurality of control orifices 49 located between opposing second ends of inlet and discharge ports 42, 44, and a plurality of associated control valves 50 connected to control orifices 48 and 49 by way of individual passages 52. Although FIG. 3 shows four control orifices 48 positioned at a transition area 54 corresponding to a top-dead-center (TDC) location of plungers 20, and four control orifices 49 positioned at a transition area 56 corresponding to a bottom-dead-center (BDC) location of plungers 20, orifice plate 23 may include any number of control orifices 48, 49 at each end-of-stroke location. A greater number of control orifices 48, 49 may increase fine control over a displacement of plungers 20, as will be described in more detail below. The TDC and BDC locations may generally be aligned with tilt axis 40 of swashplate 26, and located between first and second ends of inlet and discharge ports 42, 44, respectively.

[0024] One control valve 50 may be connected to each control orifice 48 and to inlet port 42 by way of a passage 55 to selectively change (i.e., relieve) a pressure within pumping chamber 22 and a resulting force of plungers 20 on swashplate 26 in response to a command signal. That is, the relieving of pressure within pumping chamber 22 at transition area 54 may result in less force being transmitted by plungers 20 to

one side or the other of swashplate 26 (i.e., relative to tilt axis 40). And, depending on which of control orifices 48 are communicated with inlet port 42 by way of control valves 50, a torque about tilt axis 40 may result from these force changes that functions to tilt swashplate 26 against the bias of resilient member 39 to a desired angle. For example, when one or more of control orifices 48 closer to discharge port 44 are opened to a greater extent, less force on that side of swashplate 26 may be generated, thereby allowing swashplate 26 to be tilted by resilient member 39 toward a maximum displacement position (resilient member 39 may be less compressed in this example). In contrast, when one or more of control orifices 48 closer to inlet port 42 are opened to a greater extent, less force on that side of swashplate 26 may be generated, thereby allowing swashplate 26 to tilt toward a minimum displacement position (resilient member 39 may be more compressed in this example). In this manner, control orifices 48 may be selectively opened, closed, or metered to finely control the tilt angle of swashplate 26, without requiring a dedicated tilt actuator. It is contemplated that resilient member 39 may alternatively bias swashplate 26 toward a maximum displacement or other extreme end position, if desired.

[0025] One control valve 50 may be connected to each control orifice 49 and to discharge port 44 by way of a passage 53 to selectively change (i.e., relieve or increase) a pressure within pumping chamber 22 and a resulting force of plungers 20 on swashplate 26 in response to a command signal. That is, the changing of pressure within pumping chamber 22 at transition area 56 may result in more or less force being transmitted by plungers 20 to one side or the other of swashplate 26 (i.e., relative to tilt axis 40). And, depending on which of control orifices 49 are communicated with discharge port 42 by way of control valves 50, a torque about tilt axis 40 may result from these force changes that functions to tilt swashplate 26 against the bias of resilient member 39 to a desired angle. For example, when one or more of control orifices 49 closer to discharge port 44 are opened to a greater extent, less force on that side of swashplate 26 may be generated, thereby allowing swashplate 26 to be tilted by resilient member 39 toward a maximum displacement position. In contrast, when one or more of control orifices 49 closer to inlet port 42 are opened to a greater extent, less force on that side of swashplate 26 may be generated, thereby allowing swashplate 26 to tilt toward a minimum displacement position.

[0026] Alternatively, one or more of control orifices 48, 48 may be connected to a pressure source or reservoir other than or in addition to inlet and discharge ports 42, 44. For example, each control orifice 48, 49 could be connected to a lower pressure tank 66 by way of control valves 52 and passages 53, 55. In this configuration, control valves 52 may be used to selectively relieve fluid from any of control orifices 48, 49 to tank 66.

[0027] Control valve 50 may be any type of valve such as, for example, a poppet or a spool valve. In particular, control valve 50 may include a valve element movable from a first position at which fluid is inhibited from flowing therethrough (i.e., at which fluid flow through the associated control orifice 48 or 49 is restricted), toward a second position at which fluid may freely flow. In some embodiments, control valve 50 may be a proportional valve, wherein the valve element may be moved to any position between the first and second positions to selectively adjust a restriction placed on the flow of fluid from control orifices 48 or 49. Furthermore, control valve 50 may be solenoid-actuated, hydraulically-actuated, pneumatically-actuated or actuated in any other manner to selectively

restrict or completely block the flow of pressurized fluid from control orifices 48, 49 to inlet and discharge ports 42, 44.

[0028] In an exemplary embodiment, a control system 60 may be associated with hydraulic unit 10 to regulate activation of control valves 50 in response to one or more input. Control system 60 may include a controller 62, and one or more input devices 64. In one example, input devices 64 may embody sensing devices, for example a pressure sensor, a flow sensor, a torque sensor, a speed sensor, a vibration sensor, and/or an operator input sensor. And, based on signals generated by input devices 64 indicative of actual and/or demanded performance, controller 62 may be configured to determine a desired change to the tilt angle of swashplate 26 and to responsively open, close, or meter control valves 50.

[0029] Controller 62 may embody a single or multiple microprocessors, field programmable gate arrays (FPGAs), digital signal processors (DSPs), etc. that include a means for monitoring, determining, recording, and/or controlling an operation of hydraulic unit 10 in response to signals received from input devices 64 and from other sources. Numerous commercially available microprocessors can be configured to perform the functions of controller 62. It should be appreciated that controller 62 could readily embody a microprocessor separate from that controlling other non-tilt related hydraulic unit functions, or that controller 62 could be integral with a general hydraulic unit microprocessor and be capable of controlling numerous hydraulic unit functions and modes of operation. If separate from the general hydraulic unit microprocessor, controller 62 may communicate with the general hydraulic unit microprocessor via datalinks or other methods. Various other known circuits may be associated with controller 62, including power supply circuitry, signal-conditioning circuitry, actuator driver circuitry (i.e., circuitry powering solenoids, motors, or piezo actuators), communication circuitry, and other appropriate circuitry.

INDUSTRIAL APPLICABILITY

[0030] The disclosed hydraulic unit finds potential application in any fluid system where simplified tilt angle control, high-efficiency and response, and/or noise abatement is desired. The disclosed hydraulic unit finds particular applicability in tool systems, especially tool system for use onboard mobile machines. One skilled in the art will recognize, however, that the disclosed hydraulic unit could be utilized in relation to other fluid systems that may or may not be associated with hydraulically operated tools. For example, the disclosed hydraulic unit could be utilized in relation to an engine lubrication, cooling, fueling, and/or drive system.

[0031] Referring to FIG. 2, when driveshaft 12 is rotated, body 16 and plungers 20 disposed within barrels 18 of body 16 may also rotate. As plungers 20 rotate about central axis 24, spherical ends 34 and paired slippers 36 thereof, riding along tilted plunger engagement surface 28 may cause plungers 20 to cyclically rise and fall in the axial direction of driveshaft 12 (i.e., to extend into and retract from barrels 18). This reciprocating motion may function to draw fluid into pumping chambers 22 and push the fluid from pumping chambers 22 at an elevated pressure.

[0032] During operation of hydraulic unit 10 as a pump, the flow rate and/or pressure of the fluid exiting body 16 may be varied to meet demands (i.e., a flow output demand) of the associated circuit (not shown). To increase the flow rate and/or pressure of the discharged fluid, the tilt angle of plunger engagement surface 28 may be increased, by selectively changing (i.e., reducing) a flow restriction of those of control orifices 48, 49 closer to discharge port 44 via control valves 50. Conversely, to decrease the flow rate and/or pressure of

the discharged fluid, the tilt angle may be reduced by selectively lowering a flow restriction of those of control orifices 48, 49 closer to inlet port 42 via control valves 50.

[0033] When hydraulic unit 10 is driven as a motor, pressurized fluid entering pumping chambers 22 may drive rotation of driveshaft 12. Specifically, as the pressurized fluid enters pumping chamber 22, it may be allowed to expand the volume of the pumping chamber 22. That is, the pressurized fluid may force plungers 20 against the tilted plunger engagement surface 28 of swashplate 26, thereby urging body 16 and connected driveshaft 12 to rotate. By changing the tilt angle of swashplate 26 in a motoring application, a speed and/or a torque of hydraulic unit 10 may be affected.

[0034] Control orifices 48, 49 may also or alternatively be utilized to reduce flow pulsations and/or noise of hydraulic unit 10. Specifically, based on a number of plungers 20 included within hydraulic unit 10 and a speed of hydraulic unit 10, the flow of pressurized fluid entering or exiting hydraulic unit 10 may exhibit generally sinusoidal flow pulsations in velocity and/or pressure with respect to time, as well as resulting torque pulsations on body 16, swashplate 26, and driveshaft 12. These pulsations, if unaccounted for, could create instability in the associated hydraulic system and/or be observed as undesired noise stemming from hydraulic unit 10. Control orifices 48, 49 may help to reduce the flow pulsations and the associated instability and noise, by instantaneously changing the tilt angle of swashplate 26 and/or the force of plungers 20 by a specific amount that pertains to the design of hydraulic unit 10. These instantaneous changes in plunger travel and/or force may be designed to attenuate or even cancel the above-described flow pulsations. In some embodiments, the attenuating movements generated by selective flow control of orifices 48, 49 may be initiated based on signals from input devices 64.

[0035] Because hydraulic unit includes multiple control orifices located within each of transition areas 54 and 56, fine control over swashplate tilt angle and plunger force may be provided. This fine control may improve efficiency, stability, noise, and responsiveness of hydraulic unit 10.

[0036] It will be apparent to those skilled in the art that various modifications and variations can be made to the hydraulic unit of the present disclosure. Other embodiments of the hydraulic unit will be apparent to those skilled in the art from consideration of the specification and practice of the hydraulic unit disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope being indicated by the following claims and their equivalents.

What is claimed is:

1. A hydraulic unit, comprising:

- a rotatable body at least partially defining a plurality of barrels;
- a plurality of plungers associated with the plurality of barrels;
- a swashplate tiltable to vary a displacement of the plurality of plungers relative to the plurality of barrels;
- an orifice plate located adjacent the rotatable body and having:
 - an inlet port;
 - a discharge port; and
 - a first plurality of control orifices located between first ends of the inlet and discharge ports; and
- a first plurality of control valves, each of the first plurality of control valves associated with a different control orifice of the first plurality of control orifices.

2. The hydraulic unit of claim 1, wherein each of the first plurality of control valves is configured to selectively communicate an associated one of the first plurality of control orifices with the inlet port.

3. The hydraulic unit of claim 1, wherein communication of the first plurality of control orifices with the inlet port affects a tilt angle of the swashplate.

4. The hydraulic unit of claim 1, further including:

- a second plurality of control orifices located between second ends of the inlet and discharge ports; and

- a second plurality of control valves, each of the second plurality of control valves associated with a different control orifice of the second plurality of control orifices and being configured to selectively communicate an associated one of the second plurality of control orifices with the discharge port.

5. The hydraulic unit of claim 1, further including at least one resilient member configured to urge the swashplate toward one of a minimum and a maximum displacement position.

6. The hydraulic unit of claim 1, further including a metering slot extending from an end of at least one of the inlet and discharge ports.

7. The hydraulic unit of claim 1, further including:

- a sensing device configured to generate a signal indicative of a performance demand change; and

- a controller in communication with the sensing device and the first plurality of control valves, the controller being configured to:

- determine a desired tilt angle change of the swashplate based on the performance demand change; and

- selectively activate the first plurality of control valves based on the desired tilt angle change.

8. The hydraulic unit of claim 1, wherein the performance demand change is associated with a flow output.

9. The hydraulic unit of claim 1, wherein the performance demand change is associated with at least one of a torque output, a speed, and a noise.

10. A method of pressurizing fluid, comprising:

- rotating a plurality of plungers past an inlet port during a retraction stroke of the plurality of plungers to draw in fluid;

- rotating the plurality of plungers past a discharge port during an extension stroke of the plurality of plungers to expel fluid; and

- selectively changing a force on the plurality of plungers at multiple locations near an end-of-stroke motion of the plurality of plungers to affect a displacement of the plurality of plungers.

11. The method of claim 10, where selectively changing includes selectively changing the force on the plurality of plungers at multiple locations near both a top-dead-center and a bottom-dead center of the plurality of plungers.

12. The method of claim 10, wherein changing the force on the plurality of plungers near the end-of-stroke motion affects a tilt angle of a swashplate operatively engaged with the plurality of plungers.

13. The method of claim 12, wherein changing the force on the plurality of plungers near the end-of-stroke motion affects a compression amount of a resilient member opposing tilting of the swashplate.

14. The method of claim **10**, further including gradually communicating the plurality of plungers with at least one of the inlet port and the discharge port during rotation of the plurality of plungers.

15. The method of claim **10**, further including:
sensing a performance demand change;
determining a desired displacement change of the plurality of plungers based on the performance demand; and
selectively changing the force on the plurality of plungers based on the desired displacement change.

16. The method of claim **15**, wherein the performance demand change is associated with at least one of a flow output, a torque output, a speed, a pulsation, and a noise.

17. A method of converting power, comprising:
directing pressurized fluid into a plurality of pumping chambers as the plurality of pumping chambers rotate past an inlet port;
expanding a volume of the pumping chambers with the pressurized fluid to generate a mechanical output;
discharging the pressurized fluid from the plurality of pumping chambers as the plurality of pumping chambers rotate past a discharge port; and

selectively changing a pressure of the plurality of pumping chambers at multiple locations between first ends of the inlet and discharge ports to affect the mechanical output.

18. The method of claim **17**, wherein selectively changing further includes selectively changing the pressure at multiple locations between second ends of the inlet and discharge ports to affect the mechanical output.

19. The method of claim **17**, further including gradually communicating the plurality of pumping chambers with at least one of the inlet port and the discharge port during rotation of the plurality of pumping chambers.

20. The method of claim **17**, further including:
sensing a demand change in at least one of a speed and a torque of the mechanical output;
determining a desired expansion amount based on the performance demand; and
selectively changing the pressure of the plurality of pumping chambers based on the desired expansion amount.

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