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(54) **DIELECTRIC SENSOR ARRANGEMENT AND METHOD FOR SWASHPLATE ANGULAR POSITION DETECTION**

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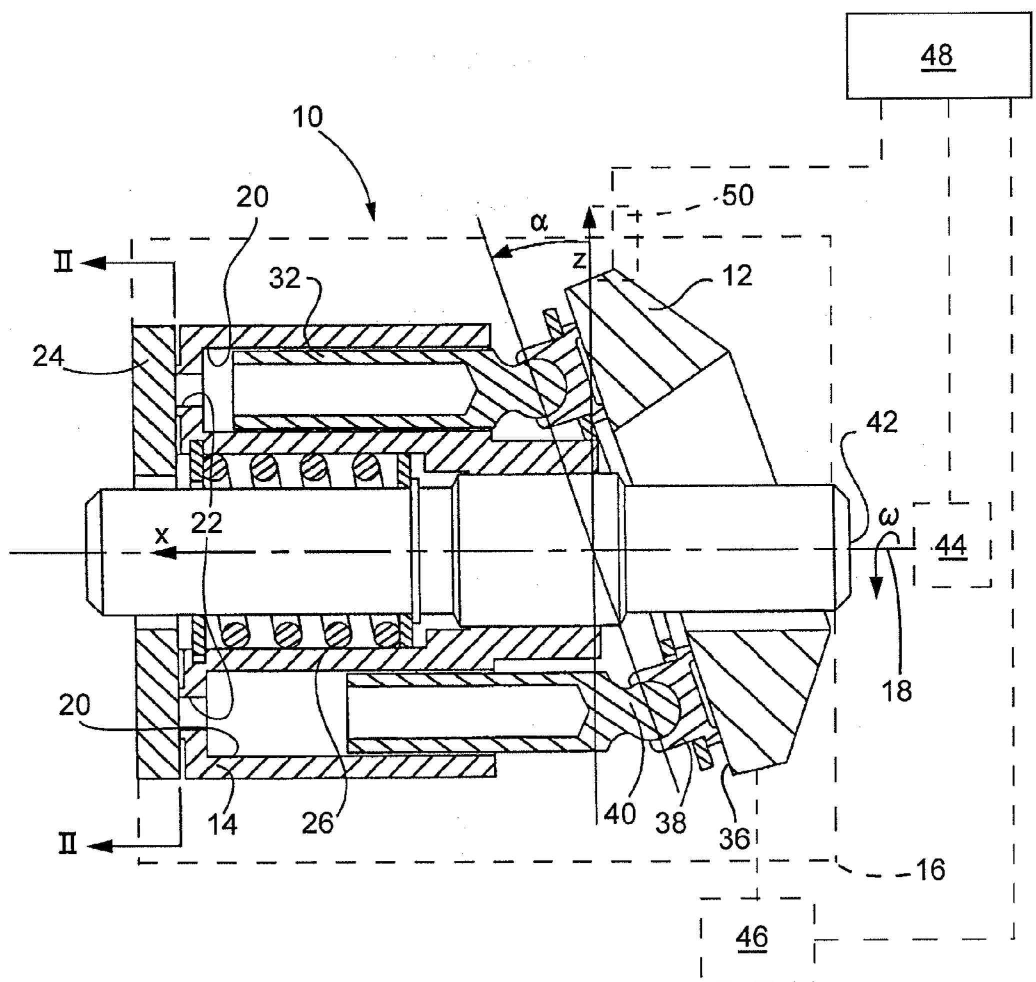
(57) **ABSTRACT**

Swashplate angle sensing arrangement for a variable displacement pump a nonrotating swashplate and a rotating pump barrel includes a dielectric sensor in a swashplate angle sensing arrangement. The arrangement includes a sensing probe coupled to the casing, a sensor target coupled to the swashplate, and a controller configured to direct an alternating current through the sensing probe to establish an impedance between the probe and the target, and to determine voltage across the probe. The controller is further adapted to determine the angle of the swashplate relative to the casing based on the determined voltage.



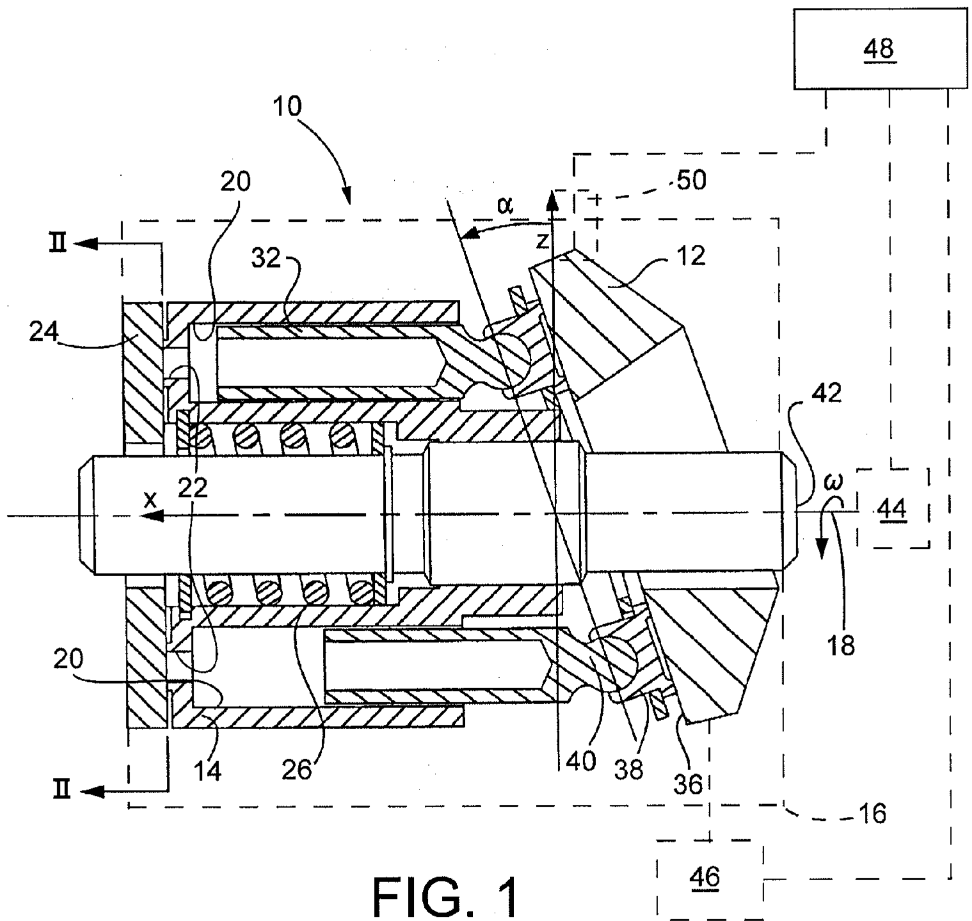

48
10
20
50
α
z
II
32
12
24
42
22
x
ω
44
18
20
40
38
36
14
26
II
16
46

FIG. 1

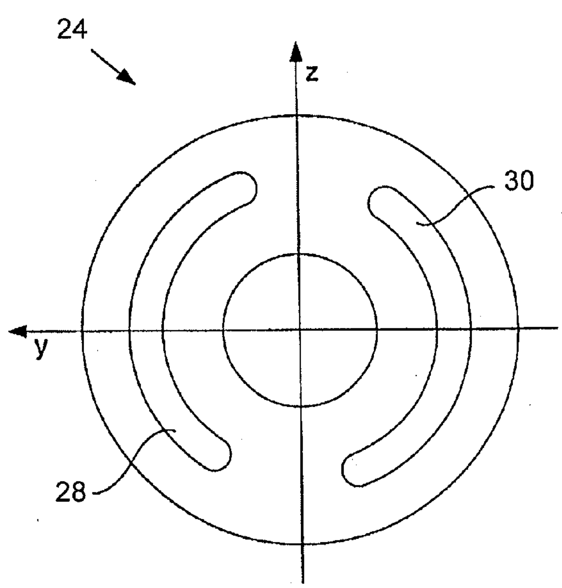

24
z
30
y
28

FIG. 2

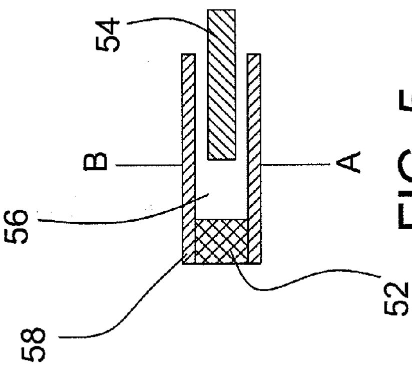


FIG. 5

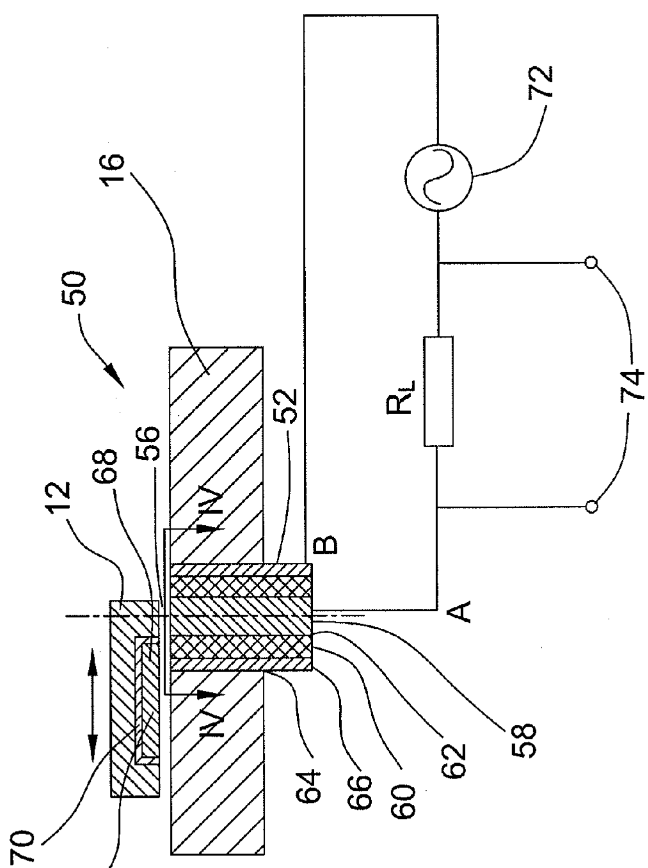


FIG. 3

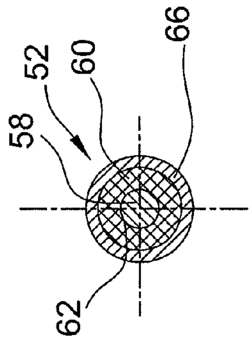


FIG. 4

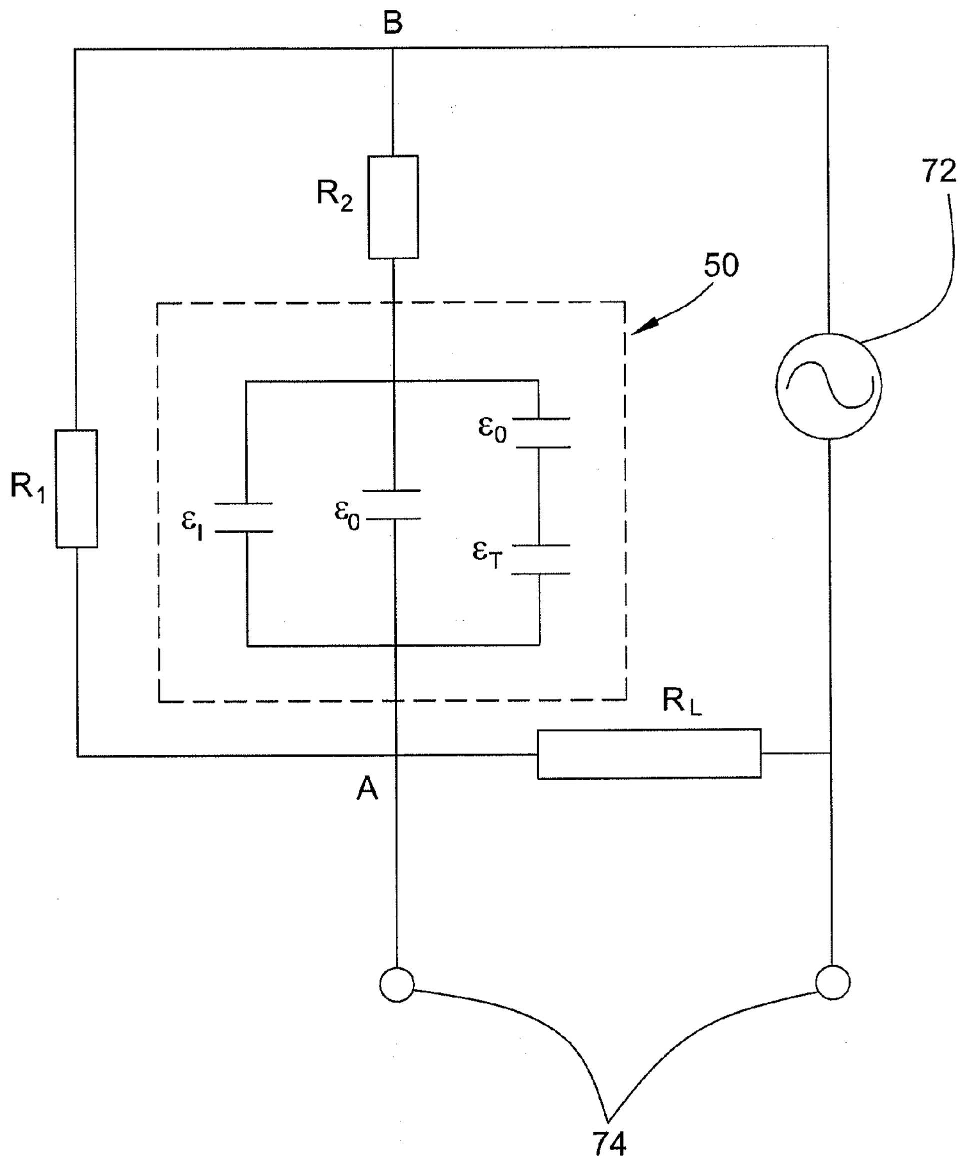

B
R_2
72
50
R_1
ε_0
ε_I
ε_0
ε_T
R_L
A
74

FIG. 6

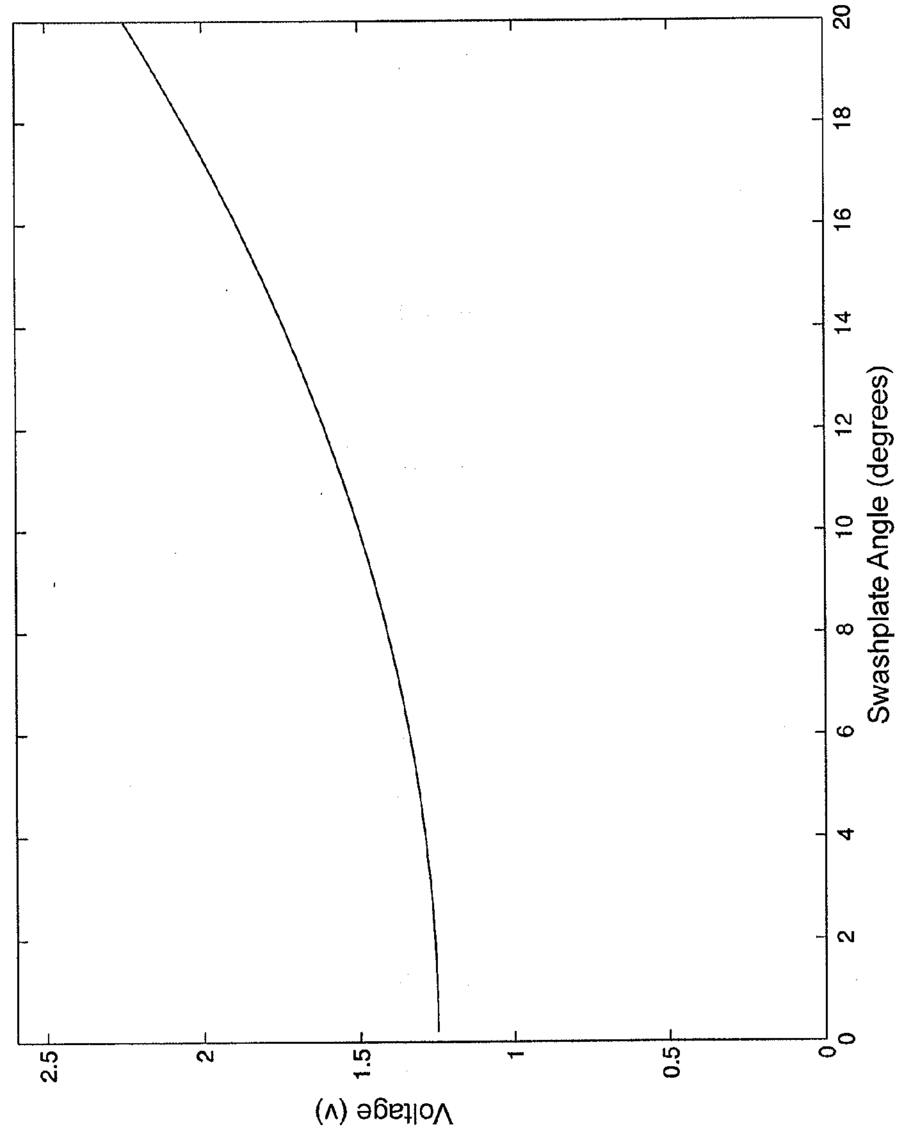

Voltage (v)
Swashplate Angle (degrees)
0
0.5
1
1.5
2
2.5
0
2
4
6
8
10
12
14
16
18
20

FIG. 7

DIELECTRIC SENSOR ARRANGEMENT AND METHOD FOR SWASHPLATE ANGULAR POSITION DETECTION

TECHNICAL FIELD

[0001] This patent disclosure relates generally to a method and apparatus for monitoring variable displacement hydraulic pumps and, more particularly, to a method and arrangement for monitoring an angle of a swashplate.

BACKGROUND

[0002] Variable displacement pumps are commonly used in many different types of hydraulic systems. Some vehicles commonly include hydraulic pumps that are driven by an engine or motor in the vehicle to generate a flow of pressurized fluid. The pressurized fluid may be used for any of a number of purposes during the operation of the vehicle. A machine, for example, may use the pressurized fluid to propel the machine around a work site or to move a work implement on the machine.

[0003] A variable displacement pump typically draws operating fluid, such as, for example, oil, from a reservoir and applies work to the fluid to increase the pressure of the fluid. The pump may include a pumping element, such as, for example, a series of pistons, that increase the pressure of the fluid. The pump may also include a variable angle swashplate that drives the pistons through a reciprocal motion to increase the pressure of the fluid.

[0004] A pump that includes a variable angle swashplate may also include a mechanism that varies the angle of the swashplate to change the stroke length of the pistons and thereby vary the displacement of the pump. The displacement of the pump may be decreased by changing the angle of the swashplate to shorten the stroke length of the pistons. Alternatively, the displacement of the pump may be increased by changing the angle of the swashplate to increase the stroke length of the pistons.

[0005] The amount of pressurized fluid required from a variable displacement pump may vary depending upon the particular operating conditions of the system or vehicle that relies upon the pump. In a vehicle application, for example, the overall efficiency of the vehicle may be improved by varying the displacement of the pump to match the requirements of the vehicle. If the vehicle requires less pressurized fluid, the angle of the swashplate may be changed to decrease the stroke length of the pistons. Conversely, if the vehicle requires more pressurized fluid, the angle of the swashplate may be changed to increase the stroke length of the piston.

[0006] A vehicle or system may include a control system that monitors the operating requirements and controls the operation of the pump to match the requirements. To effectively match the output of the pump with the requirements of the vehicle or system, the control system monitors the current output of the pump by, for example, sensing the angle of the swashplate. If the control system can accurately determine the angle of the swashplate, the control system can accurately estimate the current output of the pump. The control system can then adjust the angle of the swashplate to match the requirements of the vehicle.

[0007] A variable displacement pump may include a sensor to monitor the angle of the swashplate. A swashplate sensor may be based on any of several different principles. For example, a sensor may be based on mechanical, light, electrical, magnetic or Hall-effect principles. Typically, however, the known sensors that are based on these principles are either unsuitable for use in a variable displacement pump, may result in a significant increase in the overall cost in the pump, may not be adequately robust to withstand the demands of operation, or may be affected by interference in the system, such as ferrous material in pump fluid.

[0008] For example, one type of swashplate angle sensor, manufactured by Rexroth, is based on a combination of electrical and magnetic principles known as the Hall Effect. This sensor utilizes permanent magnets that are attached to the swashplate and which extend outside the pump casing. A Hall-effect semiconductor chip is disposed between the permanent magnets. By directing a current through the semiconductor chip and measuring the resulting voltage across the chip, the angle of the swashplate may be determined. However, obtaining an effective seal between the pump casing and the magnet projecting outside the pump casing is difficult and expensive. In addition, any magnetic materials near the sensor may interfere with the operation of the sensor. U.S. Pat. No. 6,848,888 to Du et al. attempts to overcome some of the shortcomings of prior art Hall Effect sensors.

[0009] It is desirable that a pump flow measuring arrangement would provide reliable information in a rugged working environment, regardless of temperature variations, significant system vibration, frequent pressure fluctuations, metal debris in the operating fluid of the pump, cavitations, and various noises. It is further desirable that such an arrangement be economical to manufacture and operate.

SUMMARY

[0010] According to an aspect of the disclosure, a swashplate angle sensing arrangement for a variable displacement pump having a casing containing a nonrotating swashplate adapted to pivot relative to an axis of rotation of a pump barrel is provided. The swashplate defines a swashplate angle relative to a plane substantially perpendicular to the axis of rotation of the pump barrel. The swashplate angle sensing arrangement includes a sensing probe coupled to the casing, a sensor target coupled to the swashplate, and a controller. The controller is configured to direct an alternating current through the sensing probe to establish an impedance between the sensing probe and the sensor target, and to determine the voltage across the sensing probe. The controller is further adapted to determine the angle of the swashplate relative to the casing based on the determined voltage.

[0011] According to another aspect, the disclosure provides a variable displacement pump having a casing, a barrel disposed within the casing and adapted to rotate about an axis of rotation, and a nonrotating swashplate disposed in the casing and adapted to pivot relative to the axis. The pump further includes a sensor target coupled to the swashplate, a sensing probe coupled to the casing and proximate the sensor target, and a controller. The controller is configured to direct a current across the sensing probe to establish an impedance between the sensing probe and the sensor target, and to determine the voltage across the sensing probe, the controller further adapted to determine the angle of the swashplate relative to the casing based on the determined voltage.

[0012] According to yet another aspect, the disclosure provides a method for monitoring the position of a nonrotating swashplate disposed to pivot relative to an axis in a variable displacement pump, the pump including a barrel rotatable about said axis within a casing. The method includes providing a sensor target coupled to the swashplate, and providing a sensing probe coupled to the casing and proximate the sensor target. The method further includes the steps of directing an alternating current across the sensing probe to establish an impedance between the sensing probe and the sensor target, determining the voltage across the sensing probe, and determining the angle of the swashplate relative to the casing based upon the determined voltage.

BRIEF DESCRIPTION OF THE DRAWING(S)

[0013] FIG. **1** is a schematic illustration of a swashplate angle sensing arrangement in conjunction for monitoring the angular position of a swashplate in a variable displacement pump shown in as a diagrammatic side profile cutaway view;

[0014] FIG. **2** is a diagrammatic end view of the valve plate of the pump of FIG. **1**, taken along line II-II;

[0015] FIG. **3** is a diagrammatic illustration of the swashplate angle sensing arrangement of FIG. **1**;

[0016] FIG. **4** is a view of the sensing probe taken along line IV-IV in FIG. **3**;

[0017] FIG. **5** is a representation of the dielectric characteristics of components of the swashplate angle sensing arrangement of FIG. **3**.

[0018] FIG. **6** is a representation of the equivalent dielectric analysis circuit of the arrangement of FIG. **3**.

[0019] FIG. **7** shows a diagram of a correlation of measured voltage to swashplate angle in an exemplary embodiment of a swashplate angle sensing arrangement according to the disclosure.

DETAILED DESCRIPTION

[0020] This disclosure relates to a method, system, and arrangement for controlling a variable displacement hydraulic pump **10**. More specifically, the disclosure relates to a method, system and arrangement for monitoring the angular position of a swashplate **12** in a variable displacement pump **10**. The method and arrangement are suited for a variety of physical configurations of variable displacement hydraulic pumps, and the controls may be implemented by software and a controller for virtually any system that incorporates a variable displacement pump.

[0021] An exemplary embodiment of a variable displacement pump **10** is illustrated in FIG. **1**. As shown, pump **10** includes a barrel **14** that is disposed in a casing **16** to rotate about a barrel axis **18**. Barrel **14** defines a series of chambers **20**, two of which are illustrated in FIG. **1**. The chambers **20** are typically spaced in a circular array at equal intervals about the barrel axis **18**. Each chamber **20** includes an outlet port **22**. The barrel **14** is held tightly against a valve plate **24** by means of a compressed cylinder-barrel spring **26** and pressure force within the barrel **14** itself. As may best be seen in FIG. **2**, the valve plate **24** includes an intake port **28** and a discharge port **30**, the significance of which will be explained below.

[0022] Returning to FIG. **1**, the pump **10** also includes a series of pistons **32**, and the swashplate **12**, which has a driving surface **36**. One piston **32** is slidably disposed in each chamber **20**. One end of each of the pistons **32** is disposed toward the outlet port **22** and the other end is disposed toward and biased into engagement with the driving surface **36** of the swashplate **12**. The pistons **32** are typically held against the swashplate **12** by either a fixed clearance device or a positive force hold-down mechanism, such as, for example, a spring (not shown). For purposes of this disclosure, the fixed clearance device or positive force hold-down mechanism will be referred to as a spring.

[0023] In the illustrated embodiment, each piston **32** is connected to a slipper **38**. Connection of each piston **32** with a respective slipper **38** includes a joint, such as, for example, the illustrated ball and socket joint **40**, each slipper **38** being disposed between a respective piston **32** and swashplate **12**. Each joint **40** allows for relative movement between swashplate **12** and a respective piston **32**.

[0024] The swashplate **12** may be disposed at an angle relative to casing **16**. For the purposes of the present disclosure, the angle α will be measured from a line z that is drawn perpendicularly from barrel axis **18**. One skilled in the art will recognize, however, that the swashplate angle may be measured using a different reference point.

[0025] A shaft **42** may be connected to barrel **14** by any appropriate mechanism. Rotation of the shaft **42** causes a corresponding rotation of barrel **14** about barrel axis **18**. The shaft **42** may be driven by an appropriate power source **44** (illustrated schematically), such as an engine, for example, an internal combustion engine. One skilled in the art will recognize, however, that the shaft **42** may be driven by another type of power source **44**, such as, for example, an electrical motor.

[0026] The barrel **14** rotates at a constant angular velocity ω. When barrel **14** is rotated, the combination of the angled driving surface **36** of swashplate **12** and the force of the spring (not shown) in each chamber **20** will drive each piston **32** through a reciprocating motion within each chamber **20**. As a result, each piston **32** periodically passes over each of the intake and discharge ports **28**, **30** of the valve plate **24**. The angle of inclination a of the swashplate **12** causes the pistons **32** to undergo an oscillatory displacement in and out of the barrel **14**, thus drawing hydraulic fluid into the intake port **28**, which is a low pressure port, and out of the discharge port **30**, which is a high pressure port.

[0027] The angle α of swashplate **12** relative to casing **16** controls the stroke length of each piston **32** and the displacement rate of pump **10**. Increasing the swashplate angle α will result in a greater stroke length of each piston **32**. Conversely, reducing the swashplate angle α will result in a reduced stroke length of each piston **32**. An increase in the stroke length of each piston **32** will increase the amount of fluid that is pressurized to the predetermined level during each rotation of barrel **14**. A decrease in the stroke length of each piston **32** will decrease the amount of fluid that is pressurized to the predetermined level during each rotation of barrel **14**. In an embodiment, the rotational range of swashplate **12** may be limited to a minimum displacement position of approximately negative 20° and a maximum displacement position of approximately positive 20°.

[0028] The swashplate **12** angle α of inclination may be controlled by any appropriate angle control mechanism **46**, and is typically based upon the requirements of a discharge pressure and/or discharge flow rate. The swashplate **12** angle α of inclination, for example, may be controlled by a hydraulically controlled mechanism, which may include, by way of further example, one or more actuating pistons (not shown). Such mechanisms are disclosed, for example, in U.S. Pat. Nos. 6,375,433 and 6,623,247, and will not be described further in this disclosure, as they will be familiar to those of skill in the art. One skilled in the art will recognize, however, that another type of mechanism, such as, for example, a solenoid driven actuator or a servomechanism, may be used to vary the angle α of swashplate **12**. In order to provide instruction to the angle control mechanism **46**, a controller **48** may be provided.

[0029] Controller **48** may include an electronic control module that has a microprocessor and a memory. As is known to those skilled in the art, the memory is operatively connected to the microprocessor and stores an instruction set and variables. Associated with the microprocessor and part of electronic control module may be various other known circuits such as, for example, power supply circuitry, signal conditioning circuitry, and solenoid driver circuitry, among others.

[0030] The controller **48** may be programmed to control the operation of pump **10** based on different input parameters. For example, in a machine, controller **48** may monitor the motions of a work implement or the requested movement of the machine itself to determine the demand for pressurized fluid. For example, when controller **48** determines that the pressurized fluid requirements exceed the current output of pump **10**, controller **34** may adjust angle control mechanism **46** to increase the angle α of swashplate **12** and thereby increase the displacement of pump **10**.

[0031] The controller **48** of this disclosure may be of any conventional design having hardware and software configured to perform the calculations, and send and receive appropriate signals to perform the disclosed logic. The controller **48** may include one or more controller units, and may be configured solely to perform the disclosed strategy, or to perform the disclosed strategy and other processes of the machine (not shown). The controller **48** be of any suitable construction, and may include a processor (not shown) and a memory component (not shown). The processor may be microprocessors or other processors as known in the art. In some embodiments, the processor may be made up of multiple processors. In one example, the controller **48** comprises a digital processor system including a microprocessor circuit having data inputs and control outputs, operating in accordance with computer-readable instructions stored on a computer-readable medium. Typically, the processor will have associated therewith long-term (non-volatile) memory for storing the program instructions, as well as short-term (volatile) memory for storing operands and results during (or resulting from) processing.

[0032] The processor may execute instructions for generating swashplate angle signal and controlling the angle α of the swashplate **12**, such as the methods described herein. Such instructions may be read into or incorporated into a computer readable medium, such as the memory component, or provided external to processor. In alternative embodiments, hard-wired circuitry may be used in place of or in combination with software instructions to implement a swashplate angle method. Thus, embodiments are not limited to any specific combination of hardware circuitry and software.

[0033] The term "computer-readable medium" as used herein refers to any medium or combination of media that participates in providing instructions to processor for execution. Such a medium may take many forms, including but not limited to, non-volatile media, volatile media, and transmission media. Non-volatile media includes, for example, optical or magnetic disks. Volatile media includes dynamic memory. Transmission media includes coaxial cables, copper wire and fiber optics.

[0034] Common forms of computer-readable media include, for example, a floppy disk, a flexible disk, hard disk, magnetic tape, or any other magnetic medium, a CD-ROM, any other optical medium, punch cards, paper tape, any other physical medium with patterns of holes, a RAM, a PROM, and EPROM, a FLASH-EPROM, any other memory chip or cartridge, or any other medium from which a computer or processor can read.

[0035] The memory component may include any form of computer-readable media as described above. The memory component may include multiple memory components.

[0036] The controller **48** may be enclosed in a single housing. In alternative embodiments, the controller **48** may include a plurality of components operably connected and enclosed in a plurality of housings. The controller **48** may be an integral part of a control panel and may be fixedly connected to a terminal box (not shown). In another embodiment, the controller **48** may be fixedly attached to a prime mover, a generator, and/or a frame of a machine (not shown). In still other embodiments, the controller **48** may be located in a plurality of operably connected locations including being fixedly attached to a frame, a prime mover, a generator, a terminal box, and/or remotely to the machine (not shown).

[0037] The controller **48** may be configured to generate a pump angle signal as a function of, for example, desired pump output flow or desired pump output pressure. In one embodiment, the pump angle signal may be a signal that commands the swashplate angle control mechanism **46** to modify the angle α of the swashplate **12**.

[0038] In order to determine and control flow rate from the pump **10**, it is necessary to accurately identify and control the angle α of the pump swashplate **12**. In accordance with the disclosure, a swashplate angle sensing arrangement **50** in the form of a dielectric sensor may be engaged with pump **10** to sense the angle α of swashplate **12**, as shown, for example, in FIGS. **1** and **3**. In the illustrated embodiment, the swashplate angle sensing arrangement **50** includes a sensing probe **52** and a sensor target **54** along with fluid media **56** disposed within the pump casing **16**. Those of skill in the art will understand that the sensing probe **52** and sensor target **54** should be appropriately sized for the pump **10** and utilize materials operative under the applicable working conditions for the design of the pump **10**.

[0039] In the illustrated arrangement **50**, the sensing probe **52** is coupled to and exposed to an interior of the pump casing **16**. The sensing probe **52** acts as a conductor, and may be of any appropriate design. By way of example only, referring to FIGS. **3** and **4**, the sensing probe **52** may be an conductive portion or electrode **58** mounted on a steel pump casing **16**, with a nonconductive portion, or insulator **60** separating the electrode **58** from the pump casing **16**. The electrode **58** maybe of any appropriate design, and may be, for example, a conductive metal wire. The insulator **60** likewise may be of any appropriate design formed of a non-magnetic material, such as, by way of example only, plastic, Teflon, or Plexiglas. For example, the insulator **60** may have a circular shape and may include a central opening **62** through which a metal wire electrode **58** extends. Insulator **60** may be disposed and sealed directly in an opening **64** in the pump casing **16**, or surrounded by a further conductive layer **66**, as illustrated in FIGS. **3** and **4**. The sensing probe **52** may secured to the casing **16** by any appropriate arrangement, such as, for example fasteners, such as screws or the like (not shown). Those of skill will recognize that alternate sensing probe designs may be utilized.

[0040] The sensor target **54** is disposed opposite the sensing probe **52**, that is, on the swashplate **12**. The sensor target **54** may be secured to the swashplate **12** by any appropriate arrangement, such as, for example, one or more fasteners, such as screws or the like (not shown). The sensor target **54** is disposed on the swashplate **12** at a position such that the position of the sensor target **54** relative to the sensing probe **52** varies with the position of the swashplate **12**. For example, the sensor target **54** may be disposed along an edge of the swashplate **12**.

[0041] As with the sensing probe **52**, the sensor target **54** may be of any appropriate design. In an embodiment, the sensor target **54** similarly includes a conductive portion **68** surrounded by a nonconductive portion or insulator **70**.

[0042] The swashplate angle sensing arrangement **50** further includes a controller **48**. While the controller **48** of the swashplate angle sensing arrangement is illustrated as the controller **48** configured to control the angle of the swashplate **12**, it will be appreciated that one or more controllers may be provided.

[0043] The controller **48** is configured to cause an alternating current from a power source **72** to be supplied to the sensing probe **52**. By establishing an alternating current between the electrode **58** of the sensing probe **52** and the pump casing **16**, which likewise acts as an electrode in contact with conductive layer **66**, impedance is established between the electrode **58** and the pump casing **16**, when metallic. The established impedance will depend upon both the fluid media **56** contained between the pump casing **16** and the sensor target **54** near the surface of the electrode **58**. Together, the fluid media **56** and the sensor target **54** may be referenced as media. As the angle α of the swashplate **12** changes, the media between the electrode **58** and the pump casing **16** changes. This change will consequently result in a change in the boundary conditions for the current path, and, as a result, the impedance.

[0044] Thus, in the illustrated embodiment, the nonconductive portion or insulator **60** of the sensing probe **52** and the fluid media **56** act as dielectrics placed between the neighboring electrodes and may be considered as equivalent to a combination of a capacitor and a resistor that will duplicate the current-voltage behavior for a given application. The change of the media between the casing **16**, the sensing probe **52** and the sensor target **54**, and/or the change of the geometry of the spacing between the same will result in the change of the impedance of the equivalent circuit.

[0045] The change in impedance changes the voltage V_{out} measured at output **74** across the resistor R_L. Accordingly, the swashplate angle sensing arrangement **50** is sensitive to the angle α of the swashplate **12** such that the resulting voltage V_{out} measured at the output **74** associated with the sensing probe **52** provides an indication of the angular position of the swashplate **12** in the form of a sensor signal to the controller **48**. The controller **48** may then correlate the measured voltage V_{out} at output **74** across the resistor R_L with a position of the swashplate **12**, and, accordingly, a swashplate angle α to determine the corresponding flow rate or pressure of the pump output based upon the measured voltage V_{out}, which information may be utilized in further control or alteration of the pump output.

[0046] The basic principle of the dielectric sensing arrangement may be seen in FIGS. **3**, and **5-6**. With composite media of the fluid media **56** and the sensor target **54**, the sensing probe **52** and the pump casing **16** form an electric circuit that can be considered as the combination of several individual capacitors made of three different materials (collectively identified by the reference numeral **50** in FIG. **5**). Thus, the three materials are those of the insulator **60**, the fluid media **56**, and the sensor target **54**.

[0047] In an embodiment, since the dielectrics of the insulator **60**, the fluid media **56**, and the sensor target **54** considered are non-perfect, the constants are replaced with complex numbers to account for the losses. Thus, the dielectric characteristics of the materials are represented by the following equations where $\in_T$ is the dielectric constant of the sensor target **54**; $\in_I$ is the dielectric constant of the insulator **60**; and $\in_O$ is the dielectric constant of the fluid media **56**:

$$\in_T=\in_T'-j\in_T''$$

$$\in_I=\in_I'-j\in_I''$$

$$\in_O=\in_O'-j\in_O''$$

[0048] The primed and double-primed quantities are frequency dependent. Accordingly, with fixed components, an accurate equivalent circuit for the sensing probe **52** is possible only for a single frequency in the region near the relaxation frequency.

[0049] Neglecting the resistance of the sensing probe **52**, the resistance of the pump casing **16**, and other parasitic capacitance and inductance, the swashplate angle sensing arrangement **50** can be represented by the equivalent circuit identified as reference numeral **50** in FIG. **6**. Thus, an equivalent circuit of an embodiment of a swashplate angle sensing arrangement **50** may be obtained as illustrated in FIG. **6**, where both R_1 and R_2 are internal resistances of the sensor. Under the excitation of a sinusoidal input voltage $E_i(j\omega)$, the current through the load resistor $I(j\omega)$, the output voltage across the load resistor $V_o(j\omega)$, and the voltage across the electrodes (i.e., the voltage across the electrode **58** of the sensing probe **52**, and the steel casing **16**) $V_p(j\omega)$ can all be calculated from this equivalent circuit shown in FIG. **6**.

[0050] For an embodiment, for example, the transfer functions are as follows:

$$G_I(j\omega) \approx \frac{j\omega(R_1+R_2)+1}{j\omega(R_L(R_1+R_2)+R_1R_2)C+R_L+R_1} \tag{1}$$

$$G_{Vo} \approx \frac{j\omega R_L(R_1+R_2)C+R_L}{j\omega(R_L(R_1+R_2)+R_1R_2)C+R_L+R_1} \tag{2}$$

[0051] The parameters in the transfer functions can be identified by input and output data at different frequencies around the operating point. To obtain the best sensitivity to the impedance change, parameter selections may be made such that the sensitivity of the transfer function with respect to its parameters is optimized. As an example, consider $|G|^2=GG^*$, where G^* is the complex conjugate of G. The necessary conditions for obtaining optimal sensitivity for each parameter for this case is:

$$\frac{\partial}{\partial p_j}\left(\frac{\partial}{\partial q_i}(G_{vo}(j\omega))G^*_{vo}(j\omega)\right)=0 \tag{3}$$

[0052] where q_i is the sensitive parameter, and p_j represents the design variable.

[0053] Those of skill in the art will appreciate that the resultant correlation between the measured voltage and the swashplate angle will be dependent of various factors including, but not limited to, the presence or absence of hydraulic fluid media **56** between the sensing probe **52** and the sensor target **54**, the respective materials, sizes and shapes of each of sensing probe **52**, the sensor target **54**, and the insulator **60**, and their respective impedances. A resultant correlation of voltage to angular position of the swashplate **12** for a model of an embodiment including a triangularly shaped sensor target **54** is illustrated in FIG. **7**. In this way, the relative shapes, sizes, and materials may be optimized in order to provide a desirable curve, for example, such a embodiment that provides a straight line correlation of voltage to swashplate angle.

INDUSTRIAL APPLICABILITY

[0054] The disclosed swashplate angle sensing arrangement **50** utilizes the principles of a dielectric sensing arrangement to determine the angular position of a swashplate **12**, and, accordingly, the fluid flow in a variable displacement pump **10** to be utilized in a hydraulic system. Embodiments of the disclosed arrangement may provide for better system performance.

[0055] Embodiments of the swashplate angle sensing arrangement **50** and a variable displacement pump **10** utilizing the same may provide reliable determination of the swashplate angle α. Embodiments may be very robust. Embodiments may be implemented with simplified packaging, and may be very robust and rugged in use.

[0056] Embodiments of the swashplate angle sensing arrangement **50** may provide reliable and accurate measurements, regardless of ferrite debris in the fluid media **56** contained within the pump **10**. Similarly, embodiments may provide such reliable and accurate measurements, regardless of one or more adverse operating conditions, including, for example, but not limited to, dramatic temperature variations, significant system vibration, frequent pressure fluctuations, cavitations, and various noises.

[0057] It will be appreciated that the foregoing description provides examples of the disclosed system and technique. However, it is contemplated that other implementations of the disclosure may differ in detail from the foregoing examples. All references to the disclosure or examples thereof are intended to reference the particular example being discussed at that point and are not intended to imply any limitation as to the scope of the disclosure more generally. All language of distinction and disparagement with respect to certain features is intended to indicate a lack of preference for those features, but not to exclude such from the scope of the disclosure entirely unless otherwise indicated.

[0058] The use of the terms "a" and "an" and "the" and "at least one" and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The use of the term "at least one" followed by a list of one or more items (for example, "at least one of A and B") is to be construed to mean one item selected from the listed items (A or B) or any combination of two or more of the listed items (A and B), unless otherwise indicated herein or clearly contradicted by context.

[0059] Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context.

[0060] Accordingly, this disclosure includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the disclosure unless otherwise indicated herein or otherwise clearly contradicted by context.

I claim:

1. A swashplate angle sensing arrangement for a variable displacement pump having a casing containing a nonrotating swashplate adapted to pivot relative to an axis of rotation of a pump barrel, the swashplate defining a swashplate angle relative to a plane substantially perpendicular to the axis of rotation of the pump barrel, the swashplate angle sensing arrangement comprising:

- a sensing probe coupled to the casing;
- a sensor target coupled to the swashplate; and
- a controller configured to direct an alternating current through the sensing probe to establish an impedance between the sensing probe and the sensor target, and to determine a voltage across the sensing probe, the controller further adapted to determine the angle of the swashplate relative to the casing based on the determined voltage.

2. The swashplate angle sensing arrangement of claim **1**, wherein the sensing probe includes a conductive portion exposed to an interior of the casing and a nonconductive portion disposed between the conductive portion and the casing.

3. The swashplate angle sensing arrangement of claim **2**, wherein the conductive portion includes a wire.

4. The swashplate angle sensing arrangement of claim **1** wherein the sensor target includes a conductive portion and a nonconductive portion disposed between the conductive portion and the swashplate.

5. The swashplate angle sensing arrangement of claim **1**, further including fluid media between the sensing probe and the sensor target.

6. The swashplate angle sensing arrangement of claim **1** wherein the controller is configured to direct the alternating current between the sensing probe and the casing.

7. The swashplate angle sensing arrangement of claim **6** wherein the established impedance changes as the angle of the swashplate changes.

8. The swashplate angle sensing arrangement of claim **1** wherein the established impedance changes as the angle of the swashplate changes.

9. The swashplate angle sensing arrangement of claim **7** wherein the sensing probe includes a conductive portion exposed to an interior of the casing and a nonconductive portion disposed between the conductive portion and the casing, the sensor target includes a conductive portion and a nonconductive portion disposed between the conductive portion and the swashplate, and fluid media between the sensing probe and the sensor target.

10. A variable displacement pump, comprising:

a casing;

a barrel disposed within the casing and adapted to rotate about an axis of rotation;

a nonrotating swashplate disposed in the casing and adapted to pivot relative to the axis;

a sensor target coupled to the swashplate;

a sensing probe coupled to the casing and proximate the sensor target; and

a controller configured to direct a current across the sensing probe to establish an impedance between the sensing probe and the sensor target, and to determine a voltage across the sensing probe, the controller further adapted to determine an angle of the swashplate based on the determined voltage.

11. The variable displacement pump of claim **10** further including fluid media disposed between the sensor target and the sensing probe.

12. The variable displacement pump of claim **10**, wherein the sensing probe is sealed within the casing.

13. The variable displacement pump of claim **10**, wherein the sensing probe includes a conductive portion exposed to an interior of the casing and a nonconductive portion disposed between the conductive portion and the casing.

14. The variable displacement pump of claim **10**, wherein the angle of the swashplate is determined relative to a plane substantially perpendicular to the axis of rotation.

15. The variable displacement pump of claim **10** wherein the sensor target includes a conductive portion and a nonconductive portion disposed between the conductive portion and the swashplate.

16. The variable displacement pump of claim **10** wherein the established impedance changes as the angle of the swashplate changes.

17. A method for monitoring an angle of a nonrotating swashplate disposed to pivot relative to an axis in a variable displacement pump comprising:

directing an alternating current across a sensing probe coupled to a casing of the pump to establish an impedance between the sensing probe and a sensor target coupled to the swashplate;

determining a voltage across the sensing probe; and

determining the angle of the swashplate based upon the determined voltage.

18. The method of claim **17** wherein directing an alternating current includes directing an alternating current across the sensing probe to establish an impedance between the sensing probe through fluid media disposed between the sensing probe and the sensor target.

19. The method of claim **18** wherein the sensing probe includes a conductive portion exposed to an interior of the casing and a nonconductive portion disposed between the conductive portion and the casing, the sensor target includes a conductive portion and a nonconductive portion disposed between the conductive portion and the swashplate, and the fluid media is hydraulic fluid.

20. The method of claim **17** further including changing the angle of the swashplate based upon the determined angle.

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