(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 955 379 A2

(12) # EUROPEAN PATENT APPLICATION

(43) Date of publication:
**16.12.2015 Bulletin 2015/51**

(51) Int Cl.:
***F04B 49/12*** (2006.01)

(21) Application number: **15163556.2**

(22) Date of filing: **14.04.2015**

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR**
Designated Extension States:
**BA ME**
Designated Validation States:
**MA**

(30) Priority: **14.04.2014 US 201461979291 P**

(71) Applicant: **Parker-Hannifin Corporation**
**Cleveland, Ohio 44124-4141 (US)**

(72) Inventors:
- **Heathcoat, David Mark Jr**
  **Greeneville, TN Tennessee 37745 (US)**
- **Gray, Roger**
  **Greeneville, TN Tennessee 37745 (US)**
- **Lola, Kirk Ayres**
  **Rutherfordton, NC North Carolina 27139 (US)**
- **Brock, Kerry**
  **Forest City, NC North Carolina 28043 (US)**
- **Crosby, Michael T**
  **Jonesborough, TN Tennessee 37659 (US)**

(74) Representative: **Belcher, Simon James**
**Urquhart-Dykes & Lord LLP**
**Tower North Central**
**Merrion Way**
**Leeds LS2 8PA (GB)**

(54) **HYDRAULICALLY CONTROLLED HYDROSTATIC TRANSMISSION**

(57) A hydrostatic transmission system includes a pump including a rotatable swashplate. Rotation of the swashplate effects a change in volumetric displacement of the pump. An actuator is coupled to the swashplate and effects rotation of the swashplate to change the volumetric displacement of the pump. An electronic controller is operatively coupled to the actuator and commands the actuator to effect rotation of the swashplate.

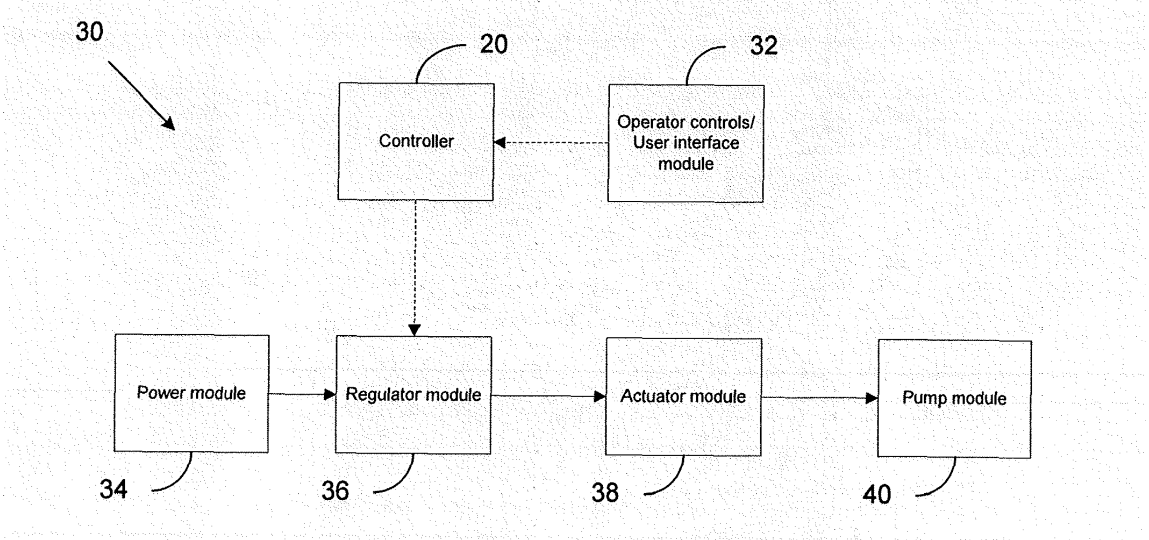


FIG. 2

EP 2 955 379 A2

## Description

**[0001]** The present invention relates generally to hydrostatic transmissions, and more particularly to pump control systems for hydrostatic transmissions.

**[0002]** Hydrostatic transmissions are well known and generally include a hydraulic pump and a hydraulic motor. The hydraulic pump and the hydraulic motor may be arranged as separate components or may be combined together in an integral unit. Axial swashplate type hydraulic piston pumps are frequently used in many such hydrostatic transmissions. Such pumps generate a pump action by causing pistons to reciprocate within a piston bore, with reciprocation of the pistons being caused by a swashplate that the pistons act against as a cylinder barrel containing the pistons rotates. Pump fluid output flow or displacement for each revolution of the barrel depends on the bore size and the piston stroke as well as the number of pistons that are utilized. The swashplate can pivot about a swashplate pivot centre or axis, and the swashplate pivot angle determines the length of the piston stroke. By changing the swashplate angle, the pump displacement can be changed as is known.

**[0003]** A maximum fluid displacement is achieved with the swashplate at its extreme pivot angle relative to the axis of rotation of the barrel. When the swashplate is centred at a right angle relative to the axis of rotation of the barrel, the pistons will not reciprocate and the displacement of the pump will be substantially zero. In some axial swashplate type piston pump designs, the swashplate has the capability of crossing over centre which results in the pump displacement being generated at opposite ports. In an over centre swashplate axial piston pump, each system port can be either an inlet or an outlet port depending on the pivot angle of the swashplate. Over centre axial swashplate piston pumps are widely used in hydrostatic transmissions, to provide driving in both forward and reverse directions.

**[0004]** One use for hydrostatic transmissions is zero turn vehicles such as zero turn lawn mowers. A separate over centre swashplate axial piston pump may drive a hydraulic motor and wheel on each side of the vehicle. When the swashplate angles of the two pumps are equal and the output flow rotates the wheels in the same direction at the same speed, the vehicle travels in a substantially straight line path in either the forward or the reverse direction. When the swashplate angles of the two pumps are not equal and the output flow rotates the wheels in the same direction but at different speeds, the output flow rotates one wheel faster than the other so that the vehicle will turn. When one of the pumps is rotating its associated wheel in one direction and the other pump is rotating its associated wheel in the other direction, the vehicle will make a zero radius turn. An operator interface allows the vehicle operator to control the swashplate angles of the separate over centre swashplate axial piston pumps, to control straight line or turning or zero radius turns for the vehicle.

**[0005]** The invention provides a system and method for controlling a hydraulic pump system. A swashplate type axial piston hydraulic pump may have a swashplate which can tilt about a swashplate tilt axis, a barrel with axial pistons disposed in the barrel, the barrel and pistons being rotatable about a barrel rotation axis relative to the swashplate, the pistons each being moveable relative to the barrel along a straight line piston path, and the pistons having a stroke determined by the position of the swashplate. A fluid-powered actuator may be drivingly connected to the swashplate for displacing the swashplate about the swashplate tilt axis in response to fluid power provided thereto. An electrical controller may generate electrical command signals in response to controller inputs, and communicate such control signals to a fluid power control device. The fluid power control device is responsive to the control signals to vary fluid power provided to the actuator and thus change a tilt angle of the swashplate.

**[0006]** The invention therefore provides a pump control system which includes: a pump including a swashplate which can tilt about a swashplate tilt axis, wherein rotation of the swashplate changes the title angle and effects a change in volumetric displacement of the pump; an actuator drivingly coupled to the swashplate, the actuator operative to displace the swashplate about the tilt axis to change the volumetric displacement of the pump; and a fluid power control device operative to vary fluid power provided to the actuator in response to a control signal; and a controller operatively coupled to the fluid power control device, the controller configured to generate the control signal to modulate the fluid power provided by the fluid power control device to the actuator to effect rotation of the swashplate.

**[0007]** Optionally, the system includes an input device operatively coupled to the controller, the input device operative to provide an input command corresponding to an output characteristic of a hydrostatic transmission, wherein the controller is configured to control an angular orientation of the swashplate based on the input command.

**[0008]** Optionally, the system includes a sensor communicatively coupled to the controller, the sensor operative to detect an angular position of the swashplate and to provide the detected angular position to the controller.

**[0009]** Optionally, the controller is configured to effect rotation of the swashplate independent of a user supplied command.

**[0010]** Optionally, the fluid power control device comprises an electronically-operated valve.

**[0011]** Optionally, the electronically-operated valve comprises a pressure control valve.

**[0012]** Optionally, the actuator comprises a hydraulic actuator.

**[0013]** Optionally, the hydraulic actuator comprises a linear actuator or a rotary actuator.

**[0014]** Optionally, the actuator is directly coupled to the swashplate.

**[0015]** Optionally, the actuator is indirectly coupled to the swashplate.

**[0016]** Optionally, the actuator comprises a ball-screw actuator.

**[0017]** Optionally, the system includes a prime-mover coupled to the pump and operative to provide mechanical power to the pump module.

**[0018]** Optionally, the system includes a hydrostatic transmission.

**[0019]** The invention also provides a zero-turn lawn mower which includes a prime mover, and a hydrostatic transmission having a swashplate control system as described herein.

**[0020]** Optionally, the system includes a method for controlling volumetric displacement of a hydraulic pump having a swashplate which can tilt about a swashplate tilt axis, wherein rotation of the swashplate changes the title angle and effects a change in volumetric displacement of the pump. An actuator is drivingly coupled to the swashplate, the actuator operative to displace the swashplate about the tilt axis to change the volumetric displacement of the pump. The method includes using an electronic controller to modulating hydraulic power provided to the actuator to effect rotation of the swashplate.

**[0021]** Optionally, the step of modulating the hydraulic power includes using a fluid power control device to modulate fluid power to the actuator.

**[0022]** Optionally, the method includes: receiving at the controller a user-initiated command corresponding to an output characteristic of the hydrostatic transmission; and controlling an angular orientation of the swashplate based on the user-initiated command.

**[0023]** Optionally, the method includes: receiving at the controller position data corresponding to an angular orientation of the swashplate; and controlling an angular orientation of the swashplate based on the position data.

**[0024]** Optionally, the step of using the electronic controller to modulate hydraulic power provided to the actuator includes modulating pressure independent of a user supplied command.

**[0025]** The invention is described below by way of example with reference to the accompanying drawings, in which:

Fig. 1 is a perspective view of a zero-turn-radius mower employing a hydrostatic transmission.

Fig. 2 is a block diagram of a control system.

Fig. 3 is a schematic diagram of a control system.

Fig. 4 is a schematic diagram showing a fluid-powered rotary actuator that may be used in a control system.

Fig. 5 is a schematic diagram of another control system.

Fig. 6 is a block diagram showing a regulator that can be used to control swashplate position.

Fig. 7 is a perspective view of components of a pump.

Fig. 8 is an enlarged perspective view of other components of a pump.

**[0026]** The invention will now be described in the context of a hydrostatic transmission of a zero-turn-radius mower. The invention is applicable to other applications in which a hydrostatic transmission is utilized.

**[0027]** Referring now to the drawings in detail, and initially to Fig. 1 which shows an example of a zero-turn-radius mower 10. The mower 10 includes a frame 12, a mower deck 14 supported by the frame 12 for mowing grass, an operator seat 16, and a plurality of controls 18 for operating the mower 10. A rear mounted engine attached to the frame 12 behind the seat 16 provides power to left and right hydrostatic transmissions also mounted to the frame 12 (the engine and hydrostatic transmissions are not shown in Fig. 1). As described below, each hydrostatic transmission includes a hydraulic pump having a swashplate, the swashplate operative to vary a volumetric displacement of the respective hydraulic pump.

**[0028]** A controller 20 is attached to the frame 12 and preferably located in an enclosure or other protected area. In the construction shown in Fig. 1 the controller 20 is located under the seat 16, although other locations are contemplated. As described below, the controller 20 is operatively coupled to the plurality of controls 18 and to the swashplate of each hydrostatic transmission. Based on commands received from the controls 18, the controller 20 can control the hydrostatic transmissions to independently drive respective rear wheels 22 to propel the mower and provide zero-turn-radius functionality.

**[0029]** With reference to Fig. 2, a block diagram shows the general architecture of a control system 30 in accordance with the present invention. More specifically, the system 30 includes the aforementioned controller 20, which can include a processor for executing instructions and a storage device, such as memory, for storing instructions executable by the processor. Alternatively, the controller 20 may be in the form of a dedicated circuit, such as an application-specific integrated circuit (ASIC) or other custom circuit.

**[0030]** The controller 20 is operatively coupled to a user interface module 32 (also referred to as an input device) to receive inputs for operating the mower 10. Generally, the user interface module 32 converts operator commands into signals that can be read by the controller 20. Thus, for example, the user interface module 32 can include the plurality of operator controls 18 and sensing devices operatively coupled thereto, the sensing devices operative to convert, for example, linear or rotary motion into signals readable by the controller 20 (e.g., analog voltage or current signals, digital signals, etc.). The signals provided to the controller 20 may correspond to a desired output characteristic of the hydrostatic transmission (e.g., speed, power, torque, swashplate position, etc.).

**[0031]** Examples of operator controls include a steering wheel, pedals, lap bars, joysticks and the like, while exemplary sensors include potentiometers, encoders, resolvers, and the like. The operator controls 18 may also include devices that provide binary on/off data, e.g., selector switches, pushbuttons and the like. Based on data received by the controller 20 from the user interface module 32, the controller 20 generates a control signal for regulating a position of a swashplate of the hydrostatic transmission.

**[0032]** A power module 34 provides fluid or electric power to the system. In some constructions, the power module 34 may be fluid power provided by a pump (e.g., pneumatic or hydraulic power). In other constructions, the power module 34 may provide electric power. Power from the power module 34 is provided to a regulator module 36.

**[0033]** The regulator module 36 receives the power provided from the power module 34 and the control signal from the controller 20. Based on the control signal from the controller 20, the regulator module 36 modulates the power (e.g., pressure or voltage) at its output and provides the modulated power to an actuator module 38. The actuator module 38 includes an actuator, such as a pneumatic, hydraulic or electric actuator, which may be in the form of a linear or rotary actuator. Modulation of the power provided to the actuator module 38 produces a desired displacement of the actuator.

**[0034]** A pump module 40 includes a hydraulic pump having a rotatable swashplate to vary displacement of the pump, the swashplate being operatively coupled to the actuator of the actuator module 38. By virtue of the coupling between the actuator and the swashplate, displacement of the actuator also effects angular displacement of the swashplate.

**[0035]** Accordingly, pump displacement (and thus power output by each hydrostatic transmission) is electronically controlled by the controller 20. Such control by the controller 20 is advantageous in that it enables rotation of the swashplate independent of a user-supplied command. Independent control can be useful for implementing custom control modes for the mower 10, such as cruise control, optimal implement speed control, four-wheel steering control, etc.

**[0036]** With additional reference to Fig. 3, a schematic representation of a control system 50 in accordance with Fig. 2 is shown for a system using hydraulically actuated swashplate. While a hydraulic system is shown in Fig. 3, other types of fluid power may be used, such as for example, pneumatic power.

**[0037]** As shown in Fig. 3 a hydrostatic transmission 52 includes a variable displacement hydraulic pump 54 for generating hydraulic power used by the hydrostatic transmission 52. The hydraulic pump 54 may be driven by a prime mover 56, such as an internal combustion engine, an electric motor or the like via drive system 58 (e.g., belt drive, chain drive, gear drive, etc.). Hydraulic power generated by the pump 54 is provided to a hydraulic motor 60 of the hydrostatic transmission 52 via ports, conduits and/or lines (not shown) within the hydrostatic transmission 52. The hydraulic motor 60 converts the hydraulic power received from the pump 54 into rotational power, which is provided at the output shaft 62 for driving wheels 22.

**[0038]** The hydraulic pump 54 includes a rotatable swashplate 64, where variation of the angular position of the swashplate 64 varies its tilt angle and thus displacement of the pump 54 (e.g., between a minimum displacement (e.g., approximately 0%) and a maximum displacement (e.g., 100%)). An angle sensor 66 monitors the swashplate 64 to detect an angular position of the swashplate 64. The sensor 66 may be in the form of an encoder, a resolver, or other suitable sensor for detecting angular position or displacement. The sensor may directly monitor position of the swashplate 66, or indirectly monitor the position of the swashplate (e.g., via a trunnion shaft).

**[0039]** Operatively coupled to the swashplate 64 are first and second hydraulic cylinders 68 and 70. The cylinders 68 and 70 may be indirectly coupled to the swashplate 64. For example, the swashplate 64 may include a trunnion shaft 73 that effects rotation of the swashplate, the trunnion shaft being coupled to the cylinders 68 and 70 via arms 68a and 70a. Alternatively, the cylinders 68 and 70 may be directly coupled to the swashplate 64. Linear displacement of the first cylinder 68 effects rotation of the swashplate 64 in a first direction, and linear displacement of the second cylinder 70 effects rotation of the swashplate 64 in a second direction opposite from the first direction.

**[0040]** The first and second cylinders 68 and 70 are in fluid communication with first and second fluid power control devices 72 and 74, respectively. First and second fluid power control devices 72 and 74, which in the present example are two-way valves, receive hydraulic power from a hydraulic power source 76, such as a fixed-displacement pump driven by the prime mover 56. Other devices may be used, e.g., three-way valves.

**[0041]** While linear actuators are used in the described construction, other types of actuators may be used instead. For example, instead of linear actuators, rotary actuators may be utilized. Briefly, Fig. 4 shows use of rotary actuators in a hydraulic system. The system is similar to the hydraulic portion of Fig. 3, except the first and second actuators 68 and 70 are replaced with a rotary hydraulic actuator 67. In response to hydraulic power provided by the fluid power control devices 72 and 74 to the rotary actuator 67, rotation of an output shaft 67a in a forward or reverse direction is achieved. The output shaft 67a may be directly coupled to the trunnion shaft 73 of the swashplate 64, or optionally a gearbox 67b may be arranged between the output shaft 67a and the trunnion shaft 73.

**[0042]** Additionally, while not shown in Fig. 3 the system can include an adjustment device to set a neutral position for the hydraulic actuators. The adjustment device is manipulated during a calibration procedure to return the cylinders 68 and 70 (or rotary actuator 67) to a neutral position and remain in that position during power loss.

**[0043]** The controller 20 includes one or more outputs for providing control signals, status signals, etc. to other devices, such as the fluid power control devices 72 and 74. For example, first and second outputs 78 and 80 of the controller are operatively coupled to the first and second fluid power control devices 72 and 74, respectively, to provide first and second control signals (e.g., analog signals such as 0 to 10 V DC or 4 to 20 mA signals) to the respective fluid power control devices 72 and 74 that are proportional to a desired fluid flow through the fluid power control devices, or proportional to a desired fluid pressure at the output of the fluid power control devices. In this regard, 0 V DC (or 4 mA) may correspond to no fluid flow or no pressure, while 10 V DC (or 20 mA) may correspond to 100% fluid flow or 100% pressure. In this manner, the controller 20 can control the delivery of fluid power to the actuators 68 and 70. While analog signals are described in the present example, other signal types may be used. For example, instead of using outputs embodied as analog outputs, control signals may be communicated to the valves 72 and 74 (or other devices) via a communication bus (e.g., a network). The controller may include additional outputs that may be used by the system, such as wheel speed reference signals, implement speed reference signals, or any other parameter that may be controlled by the controller 20. Such outputs may be used to provide enhanced control functions.

**[0044]** The controller 20 includes one or more inputs for receiving data from other devices, such as the operator controls 18. For example, the controller 20 includes a first input 82 for receiving an input command from a user-operated device, such as a speed command, a power command, a direction command, etc. For sake of clarity only one input is shown for the operator controls. However, the controller 20 may have a plurality of inputs as needed for the respective operator controls. As discussed above, the user operated device may be coupled to a sensor 86 so as to convert linear or rotary motion into a signal readable by the controller 20. The controller 20 also includes a second input 84 communicatively coupled to the angle sensor 66 for receiving data corresponding to an angular position of the swashplate 64. The controller 20 may optionally include other inputs for detecting various parameters, such as, for example, power take off engaged/ disengaged, prime mover speed, implement speed, wheel speed, or any other parameter that may be used by the controller 20. The inputs may be analog inputs (e.g., 0 to 10 V DC, 4 to 20 mA, etc.), digital inputs, optical inputs, networks, or other conventional means for providing data to the controller 20.

**[0045]** Fig. 5 shows another control system 50' which is similar to the system 50 of Fig. 3, except that electrically-operated actuators are used instead of hydraulically operated actuators. More particularly, the hydrostatic transmission 52 and its subcomponents (hydraulic pump 54 and swashplate 64, hydraulic motor 60), the prime mover 56, drive system 58, angle sensor 66, controller 20 and associated I/O are the same as those in the system of Fig. 3. Therefore, discussion of these components will be omitted for Fig. 5.

**[0046]** The system 50' includes first and second electrically-operated actuators 69 and 71 operatively coupled to the swashplate 64. Stepper motors, servo motors, shape memory alloys and piezoelectric actuators are examples of electrically-operated actuators that may be used. The electrically-operated actuators 69 and 71 may be indirectly coupled to the swashplate 64. For example, the swashplate 64 may include a trunnion shaft 73 that effects rotation of the swashplate 64, and the trunnion shaft may be coupled to the electrically-operated actuators 69 and 71 by means of arms 68a and 70a. Alternatively, the electrically-operated actuators 69 and 71 may be directly coupled to the swashplate 64. Linear displacement of the first electrically-operated actuator 69 effects rotation of the swashplate 64 in a first direction, and linear displacement of the second electrically-operated actuator 71 effects rotation of the swashplate 64 in a second direction opposite from the first direction.

**[0047]** While linear electrically-operated actuators are used in the described construction, other types of electrically-operated actuators may be used. For example, rotary actuators may be used. In one construction, the linear actuator may be a motor-driven ball-screw arrangement.

**[0048]** The electrically-operated actuators 69 and 71 receive power from an electrical power source 77. The electrical power source 77, for example, may be an alternator or generator driven by the prime mover 56. Alternatively, the electrical power source 77 may be a battery.

**[0049]** The electrically-operated actuators 69 and 71 are operatively coupled to the controller 20 via outputs 78 and 80. The outputs may be analog outputs that provide a voltage or current control signal as described with reference to Fig. 3, a communication network that provides digital control signals to the actuators, or any other means for communicating the control signals to the actuators 69 and 71. Based on the control signals, the electrically operated actuators 69 and 71 rotate the swashplate 64 into any one of a number of different positions, and may be considered infinitely variable.

**[0050]** Regardless of the form of the actuators (i.e., hydraulic or electric), the controller 20 includes logic configured to position the swashplate 64 so as to produce a desired characteristic from the hydrostatic transmission 52 (e.g., output power, output speed, output torque, etc.). The logic may be stored in memory of the controller 20 and executable by a processor of the controller 20. The logic stored in the controller 20 may be configured to control the position of the swashplate 64 based on a user-command provided by the plurality of controls 18. For example, the plurality of user-operated controls 18, such as a foot-operated pedal, a hand-operated lever, or the like can be operatively coupled to a respective sensor 86 to provide a signal corresponding to displacement of the pedal or lever (or other device). The signal generated by the sensor 86 can be provided to the controller 20 via the first input 82. The controller 20 can equate a low end of the signal range (e.g., 0 V DC, 4 mA) to a first angular position of the swashplate 64 corresponding to minimum pump displacement, and a high end of the signal range (e.g., 10 V DC, 20 mA) to a second angular position of the swashplate 64 corresponding to a maximum pump displacement. The user-input signal may be filtered and scaled as is conventional.

**[0051]** The logic executed by the controller 20 may include a position regulator for controlling a position of the swashplate 64. In this regard, the signal generated from the sensor 86 can be a "reference" position for the swashplate 64, and the signal provided by the angle sensor 66 can be the "actual" position of the swashplate 64. Based on a difference between the reference position and the actual position, the position regulator may generate a control signal, which may be filtered and scaled as is conventional. The control signal may be provided to one of the fluid power control device 72 and 74 (or to the electrically-operated actuators 69 and 71) via the outputs 78 and 80 of the controller 20. In response to the control signal, the fluid power control devices 72 or 74 will alter the fluid flow and/or fluid pressure provided to the actuators 68 or 70, thereby causing actuator displacement and effecting rotation of the swashplate 64. Alternatively, in response to the control signal the electrically-operated actuators 69 and 71 will utilize the electrical power from the power source 77 to produce actuator displacement, thus effecting rotation of the swashplate 64.

**[0052]** With reference to Fig. 6, a position regulator 100 is shown in block form, the position regulator 100 being executable by the controller 20 to control an angular orientation of the swashplate 64. Beginning at block 102, the controller 20 receives the user input signal for controlling a feature of the hydrostatic transmission, e.g., output velocity. The user input signal may be a signal obtained from the user interface module 32. For example, and as described herein, the user may manipulate an operator control 18, which in turn causes a sensor 86 coupled to the operator control 18 to generate a signal. The signal, which may be an analog signal, a digital signal, an optical signal or any other signal readable by the controller 20, preferably is proportional displacement of the respective operator control. The generated signal is read by the controller 20 via an input module corresponding to the type of signal (e.g., an analog voltage signal would be input via an analog voltage input). Next at block 104 the user input signal is optionally scaled and filtered to produce a signal corresponding to the regulated parameter. In the example shown in Fig. 6, the user input signal may be scaled to correspond to the feedback device coupled to the swashplate (i.e., sensor 66). In this regard, the user input signal could be scaled to correspond to swashplate angular orientation. Based on such scaling, the output of block 104 is a position reference signal and is provided to a positive input of summing junction 106.

**[0053]** As described herein, an angular position of the swashplate 64 is detected by sensor 66 and is provided to the controller 20 at block 108. The sensor signal may be analog, digital, optical or any other signal type readable by the controller 20. Next at block 110, the position feedback signal is optionally scaled and filtered to correspond to the position reference signal, and the position feedback signal then is provided to a negative input of summing junction 106. The output of the summing junction is an error signal indicative of the error between the desired position of the swashplate 64 and the actual position of the swashplate 64. The error signal is provided to an input of controller 112, which is shown as a proportional-plus-integral-plus-derivative (PID) controller, although other controllers may be used (e.g., a proportional controller, a proportional-plus-integral controller, etc.).

**[0054]** Based on the error signal the controller 112 generates a control signal, which is output by the controller at block 114 and provided to the actuator (e.g., to one of the fluid power control devices 68 or 70 in Fig. 3 or to one of the electrical actuators 69 and 71 in Fig. 5). In response to the control signal, displacement of the actuator and thus of the swashplate 64 is effected.

**[0055]** While this construction is described in the context of a position regulator, other regulation schemes may be used. For example, a speed regulator, torque regulator, power regulator, etc. may be used instead of or in conjunction with the position regulator.

**[0056]** Referring now to Figs.7 and 8, each hydrostatic transmission 52 includes a conventional over centre swashplate type axial piston hydraulic pump 54, which includes an input 120 that is drivingly connected to prime mover 56 to rotate a conventional pump barrel 122. A plurality of axial pistons 124 are disposed within the pump barrel 122 and rotate with the pump barrel 122 about a barrel axis 126. Pump 54 also includes a conventional over centre swashplate 64 which can tilt about a swashplate tilt axis 128. The pistons 124 are each moveable relative to the barrel along a straight line piston path 130 that is substantially parallel to the barrel rotation axis 126, and the pistons 124 have a stroke determined by the position of the swashplate 64. When the swashplate 64 is in a neutral or centre position perpendicular to the barrel axis 126, the stroke of the pistons 124 is substantially zero and the output fluid flow displacement from the pump 54 is substantially zero. When the swashplate 64 begins to be displaced or titled in either direction about its tilt axis 128, the stroke of pistons 124 begins to increase and output fluid flow displacement from the pump 54 begins. As the tilt angle of the swashplate 64 increases, the stroke of pistons 124 increases and the output fluid flow displacement from the pump 54 increases in a known manner. The output fluid flow displacement from pump 54 will be in one direction when the swashplate 64 is tilted in one direction from its neutral position and will be in the other direction when the swashplate 64 is tilted in the opposite direction. The output fluid flow from each pump 54 of each hydrostatic transmission flows through conduits (not shown) to a hydraulic motor 60 (Fig. 3) of each hydrostatic transmission 52, and such output flow rotates its associated hydraulic motor 60 to rotate its associated wheel 22 in the forward or reverse direction in a known manner. A reservoir 132 provides hydraulic fluid to the pump 54, and a lever 134 opens and closes a fluid bypass route (not shown) to enable pushing vehicle 10 when required.

## Claims

**1.** A pump control system, comprising:

a pump including a swashplate which can tilt about a swashplate tilt axis, in which rotation of the swashplate changes the title angle and effects a change in volumetric displacement of the pump;
an actuator drivingly coupled to the swashplate, the actuator operative to displace the swashplate about the tilt axis to change the volumetric displacement of the pump; and
a fluid power control device operative to vary fluid power provided to the actuator in response to a control signal; and
a controller operatively coupled to the fluid power control device, the controller configured to generate the control signal to modulate the fluid power provided by the fluid power control device to the actuator to effect rotation of the swashplate.

**2.** The pump control system according to claim 1, further comprising an input device operatively coupled to the controller, the input device operative to provide an input command corresponding to an output characteristic of a hydrostatic transmission, in which the controller is configured to control an angular orientation of the swashplate based on the input command.

**3.** The pump control system according to claim 1 or claim 2, further comprising a sensor communicatively coupled to the controller, the sensor operative to detect an angular position of the swashplate and to provide the detected angular position to the controller.

**4.** The pump control system according to any one of claims 1 to 3, in which the controller is configured to effect rotation of the swashplate independent of a user supplied command.

**5.** The pump control system according to any one of claims 1 to 4, in which the fluid power control device comprises an electronically-operated valve.

**6.** The pump control system according to claim 5, in which the electronically-operated valve comprises a pressure control valve.

**7.** The pump control system according to any one of claims 1 to 6, in which the actuator comprises a hydraulic actuator.

**8.** The pump control system according to claim 7, in which the hydraulic actuator comprises a linear actuator or a rotary actuator.

**9.** The pump control system according to any one of claims 1 to 8, in which the actuator comprises a ballscrew actuator.

**10.** A zero-turn lawn mower, comprising:

a prime mover; and
a hydrostatic transmission, the hydrostatic transmission including the swashplate control system according to any one of claims 1 to 9.

**11.** A method for controlling volumetric displacement of a hydraulic pump having a swashplate tiltable about a swashplate tilt axis, in which rotation of the swashplate changes the title angle and effects a change in volumetric displacement of the pump, and an actuator drivingly coupled to the swashplate, the actuator operative to displace the swashplate about the tilt axis to change the volumetric displacement of the pump, the method comprising using an electronic controller to modulating hydraulic power provided to the actuator to effect rotation of the swashplate.

**12.** The method according to claim 11, in which modulating hydraulic power includes using a fluid power control device to modulate fluid power to the actuator.

**13.** The method according to any one of claims 11 to 12, further comprising:

receiving at the controller a user-initiated command corresponding to an output characteristic of the hydrostatic transmission; and
controlling an angular orientation of the swashplate based on the user-initiated command.

**14.** The method according to any one of claims 11 to 13, further comprising:

receiving at the controller position data corresponding to an angular orientation of the swashplate; and
controlling an angular orientation of the swashplate based on the position data.

**15.** The method according to any one of claims 11 to 14, in which using the electronic controller to modulate hydraulic power provided to the actuator includes modulating pressure independent of a user supplied command.

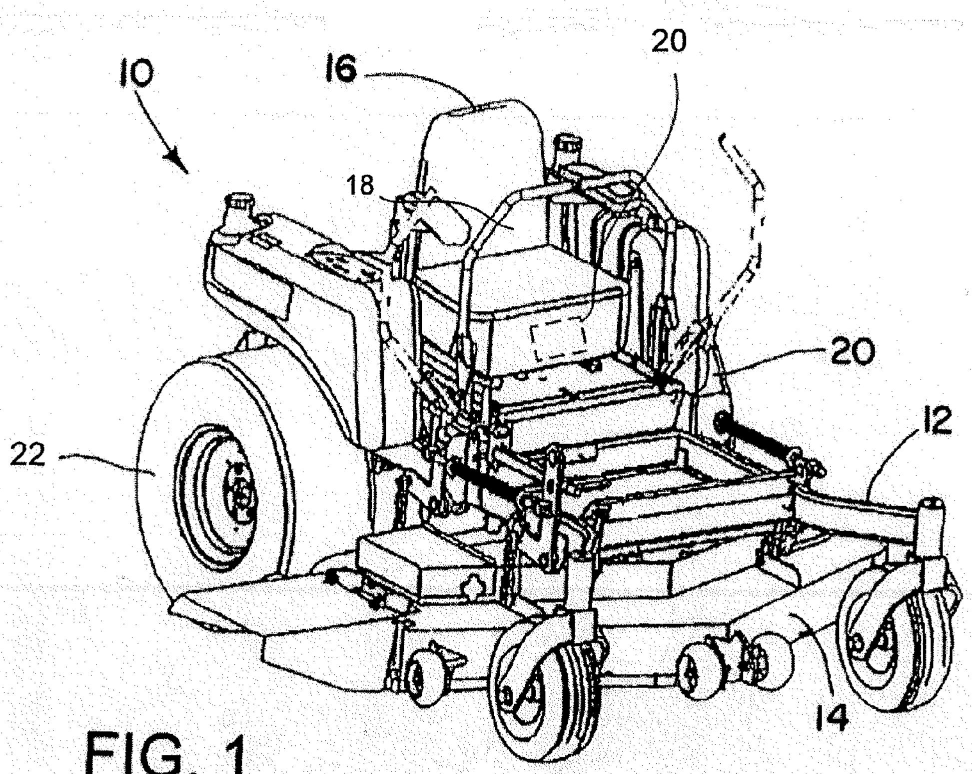
10
16
20
18
20
12
22
14

FIG. 1

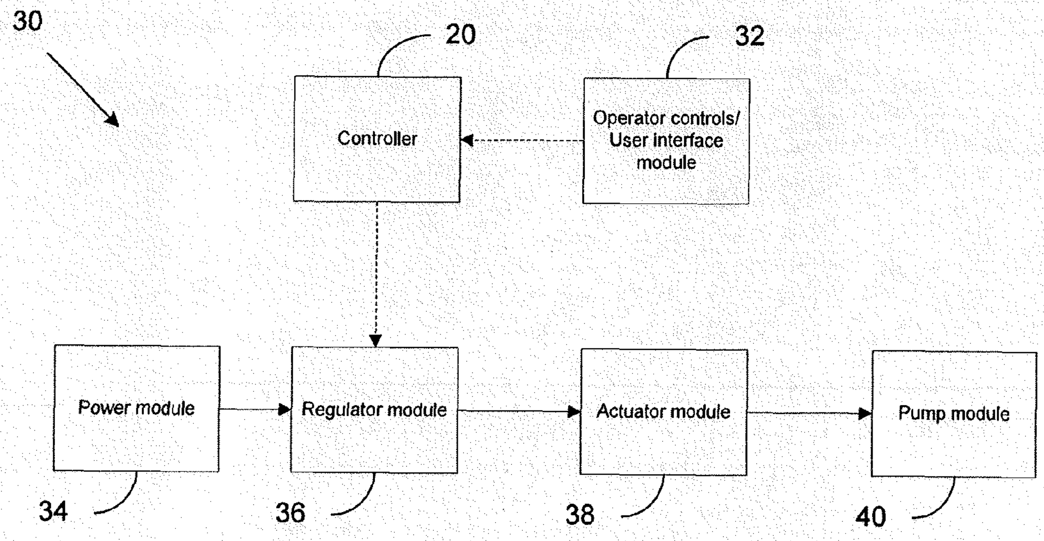
30
20
32
Controller
Operator controls/
User interface
module
Power module
Regulator module
Actuator module
Pump module
34
36
38
40

FIG. 2

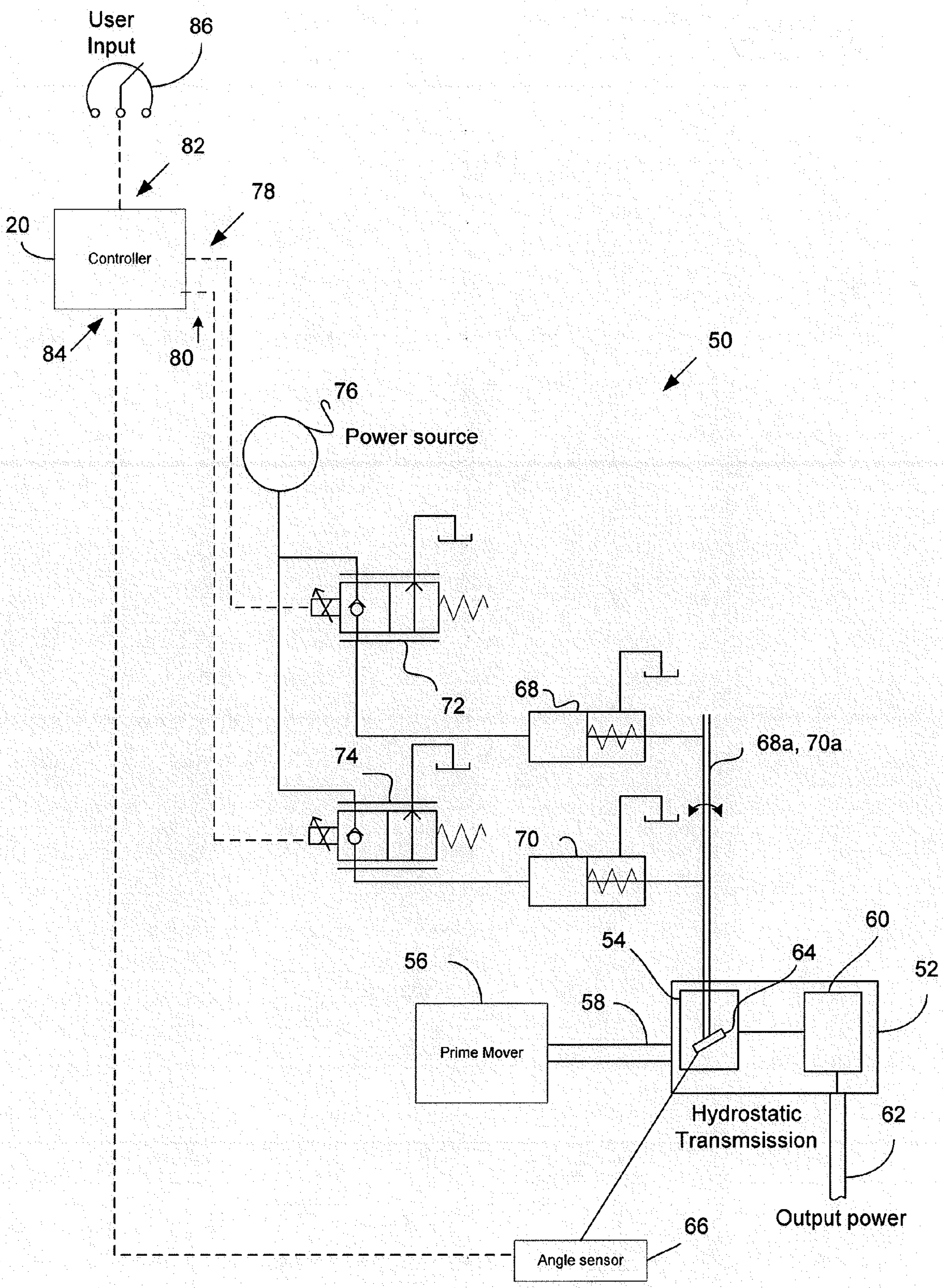
User
Input
86
82
78
20
Controller
84
80
50
76
Power source
72
68
68a, 70a
74
70
60
54
64
52
56
58
Prime Mover
Hydrostatic
Transmsission
62
Output power
66
Angle sensor

FIG. 3

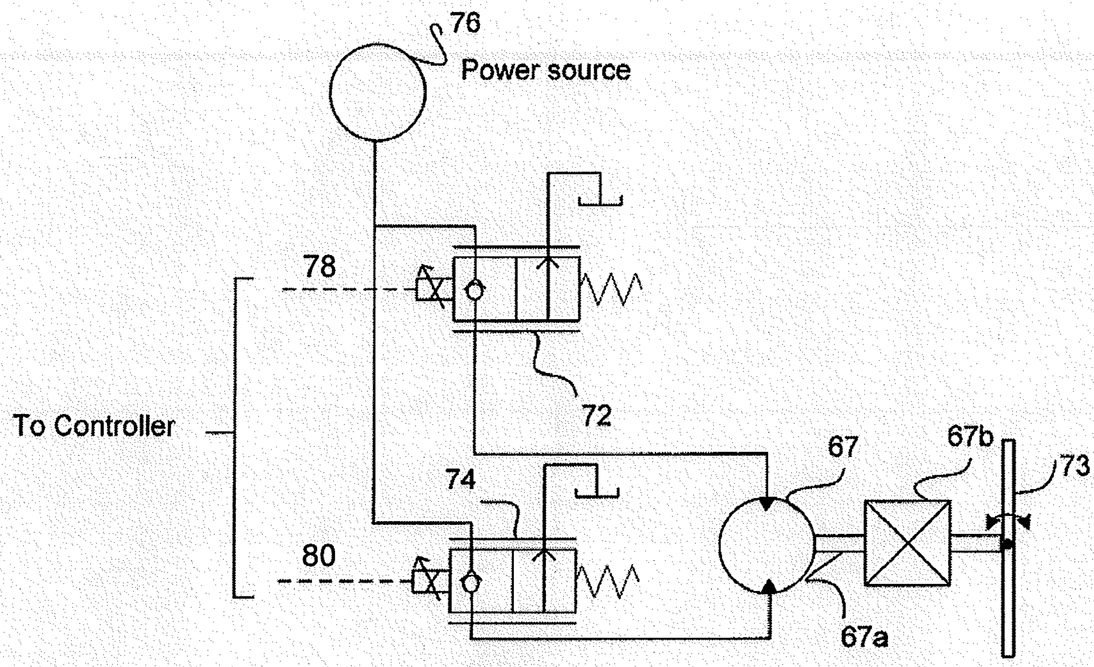


FIG. 4

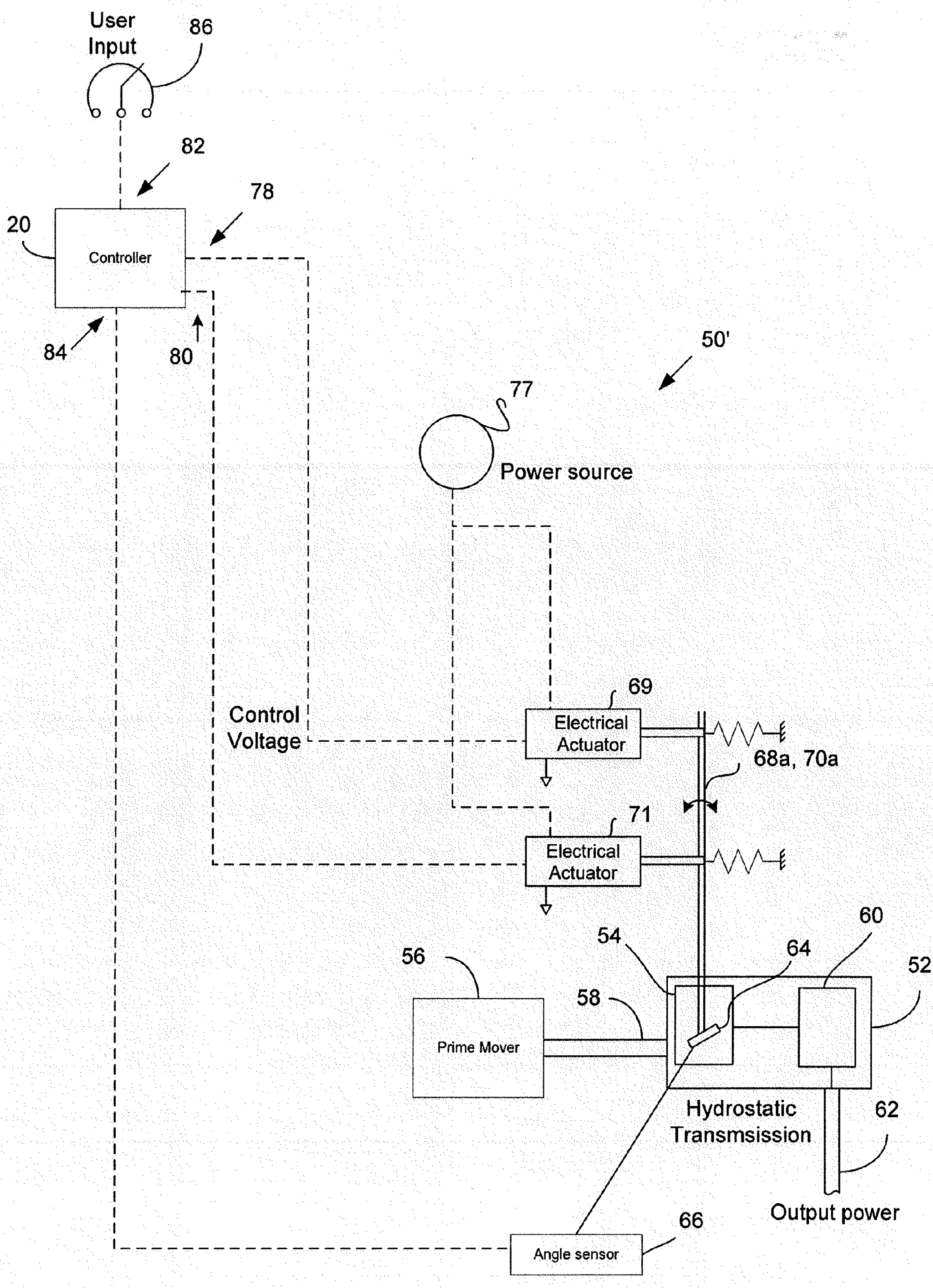
User Input
86
82
78
20
Controller
84
80
50'
77
Power source
69
Control Voltage
Electrical Actuator
68a, 70a
71
Electrical Actuator
60
54
64
52
56
58
Prime Mover
Hydrostatic Transmsission
62
Output power
66
Angle sensor

FIG. 5

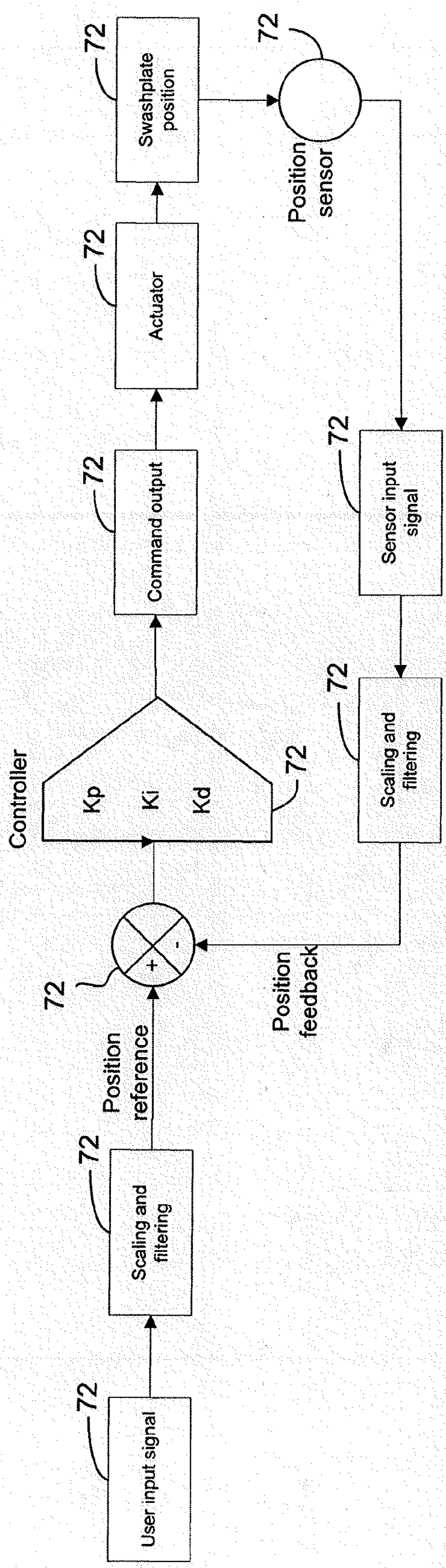
User input signal
Scaling and filtering
Position reference
+
-
Controller
Kp
Ki
Kd
Command output
Actuator
Swashplate position
Position sensor
Sensor input signal
Scaling and filtering
Position feedback
72

FIG. 6

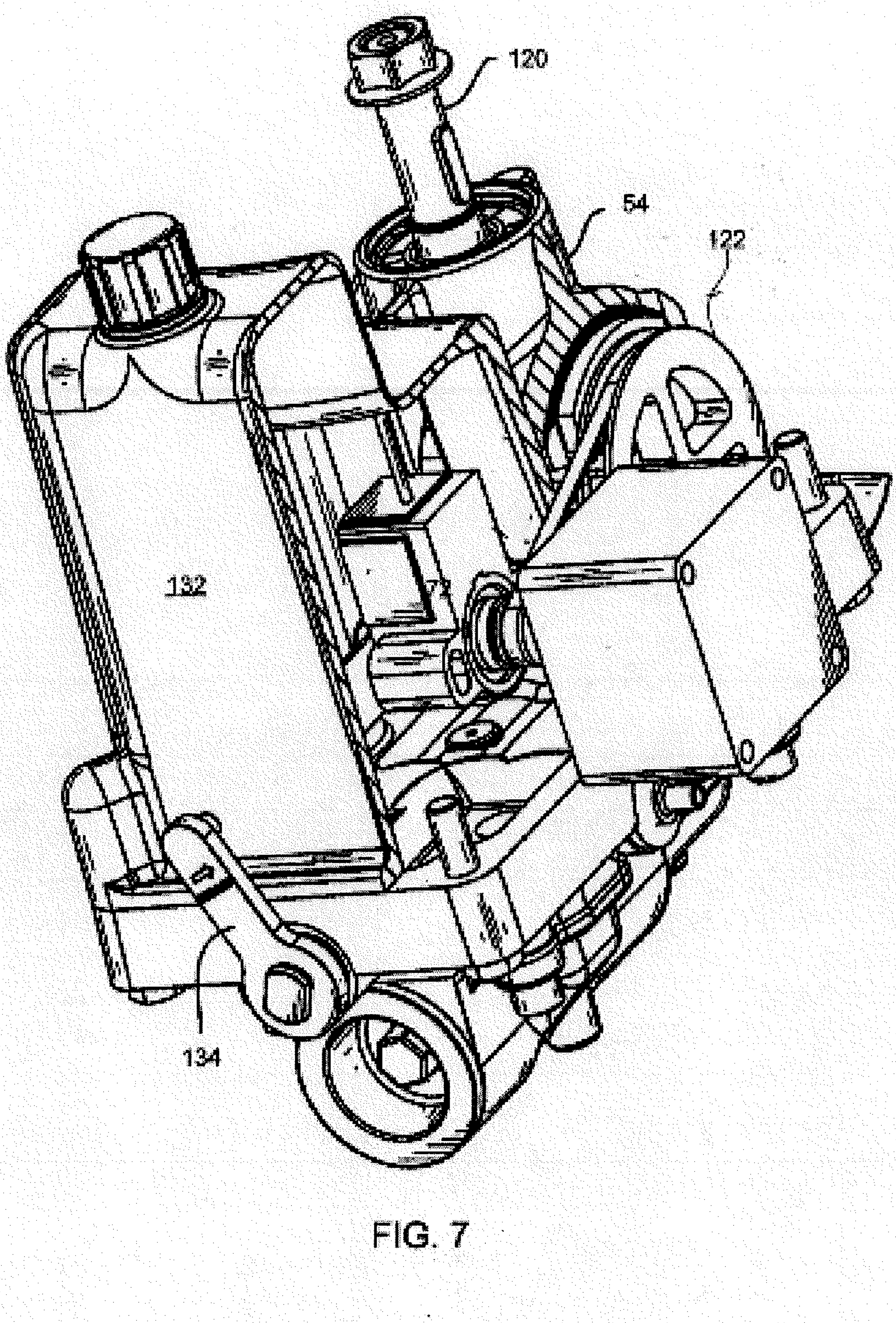


FIG. 7

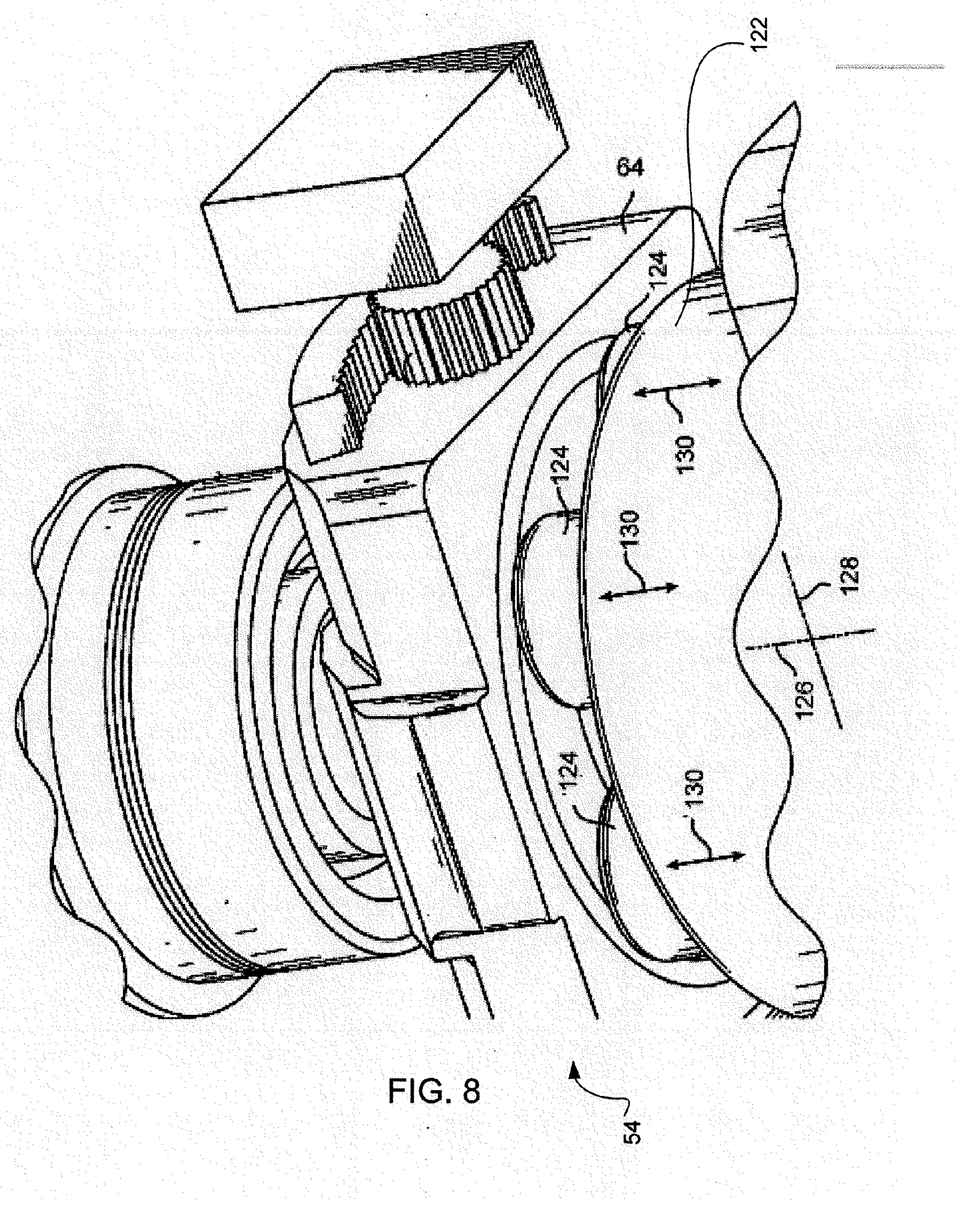


FIG. 8