



EUROPEAN PATENT APPLICATION

(43) Date of publication:
01.02.2023 Bulletin 2023/05

(51) International Patent Classification (IPC):
E02F 9/22 (2006.01) **F04B 49/06** (2006.01)
F15B 21/08 (2006.01)

(21) Application number: **21187784.0**

(52) Cooperative Patent Classification (CPC):
E02F 9/221; F04B 49/06; F15B 21/08; F15B 21/082

(22) Date of filing: **26.07.2021**

(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:
KH MA MD TN

- **TORRANCE , Bennett**
6430 Nordborg (DK)
- **SZCZEPANIAK, Connor**
6430 Nordborg (DK)
- **PELLEGRI, Matteo**
6430 Nordborg (DK)
- **HUTCHESON, John**
6430 Nordborg (DK)
- **ANDERSON, Douglas P.**
6430 Nordborg (DK)
- **ABRAHAMS, Daniel**
6430 Nordborg (DK)

(71) Applicant: **Danfoss Scotland Limited**
Edinburgh EH3 9DQ (GB)

(72) Inventors:
• **WILLIAMSON, Christopher**
6430 Nordborg (DK)
• **WADSLEY, Luke**
6430 Nordborg (DK)

(74) Representative: **Hindles Limited**
Clarence House
131-135 George Street
Edinburgh, EH2 4JS (GB)

(54) **CONTROLLER AND HYDRAULIC APPARATUS USING FLUCTUATION SIGNALS FOR HYDRAULIC ACTUATOR OPERATIONS**

(57) There is provided a controller (320) for a hydraulic machine (310), the hydraulic machine (310) in a hydraulic circuit including a hydraulic actuator, having a rotatable shaft in driven engagement with a prime mover, and defining a plurality of working chambers in the hydraulic circuit, each working chamber being defined partially by a movable working surface mechanically coupled to the rotatable shaft, such that, in operation, the hydraulic machine (310) exchanges energy with the hydraulic circuit and the prime mover by movement of the working surfaces and the rotatable shaft. The controller (320) is configured to: receive a movement input signal indicative of a demand to move the hydraulic actuator; determine a hydraulic machine control signal depending on the movement input signal and a fluctuation input signal; and control the hydraulic machine (310) to exchange hydraulic fluid with the hydraulic circuit in accordance with the hydraulic machine control signal to cause movement of the hydraulic actuator in accordance with the movement input signal and the fluctuation input signal.

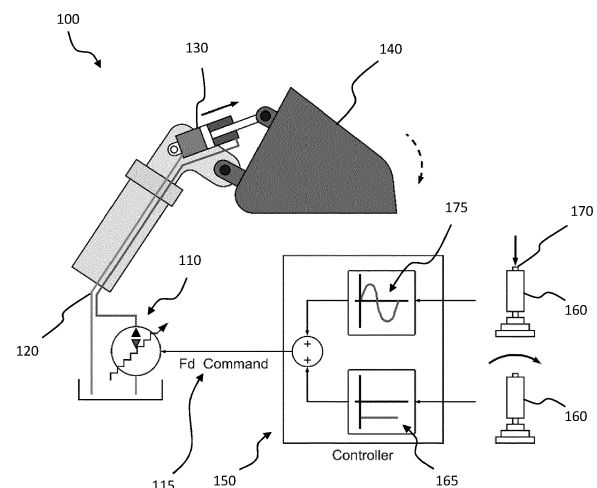


Fig. 1

Description

Field of the invention

[0001] The present invention relates to a controller for a hydraulic machine, and to a hydraulic apparatus.

Background to the invention

[0002] In several industrial applications, it can be beneficial to introduce vibration into moving mechanical components to improve efficacy. For example, in an excavator, vibration of the bucket can improve the emptying of the bucket of dirt or soil, or can improve the ability of the edge of the bucket to penetrate into a region of material to be excavated.

[0003] It is known to introduce the vibration manually, for example by an operator alternating the direction of requested movement of the mechanical component. In other examples, a dedicated vibration component can be used which is arranged to introduce a required vibration to the movement of the mechanical component.

[0004] It is in this context that the present inventions have been devised.

Summary of the invention

[0005] In accordance with an aspect of the present inventions, there is provided a controller for a hydraulic machine, the hydraulic machine in a hydraulic circuit including a hydraulic actuator, having a rotatable shaft in driven engagement with a prime mover, and defining a plurality of working chambers in the hydraulic circuit. Each working chamber is defined partially by a movable working surface mechanically coupled to the rotatable shaft, such that, in operation, the hydraulic machine exchanges energy with the hydraulic circuit and the prime mover by movement of the working surfaces and the rotatable shaft. The controller is configured to: receive a movement input signal indicative of a demand to move the hydraulic actuator; determine a hydraulic machine control signal depending on the movement input signal and a fluctuation input signal; and control the hydraulic machine to exchange hydraulic fluid with the hydraulic circuit in accordance with the hydraulic machine control signal to cause movement of the hydraulic actuator in accordance with the movement input signal and the fluctuation input signal.

[0006] Thus, the hydraulic machine is controlled taking into account both the movement input signal indicative of the demand to move the hydraulic actuator, as well as the fluctuation input signal. Operation of the hydraulic machine causes the hydraulic actuator to move in accordance with both the movement input signal and the fluctuation input signal. Accordingly, the fluctuation in the movement of the hydraulic actuator can be caused by controlling the operation of the hydraulic machine, rather than through a separate component to introduce the fluctuation in movement, or through a manual fluctuation introduced by an operator directly when generating the movement input signal. As a result, fluctuation in the movement of the hydraulic actuator can be achieved using a system having fewer components and/or without requiring constant fluctuation of the input provided by an operator.

[0007] It will be understood that a fluctuation input signal is typically any signal indicative of a demand to cause a deviation in the movement of the hydraulic actuator, during the movement (including where the demanded movement is zero) of the hydraulic actuator in accordance with the movement input signal. The deviation may be a controlled deviation. Initiating or stopping the fluctuation input signal may be used to control an onset of deviation, and initiating or stopping the signal may be used to control a ceasing of deviation in the movement. The deviation may be sustained for a significant time. The deviation may be an oscillation.

[0008] In some examples, the controller may be configured to receive the fluctuation input signal. In other examples, the fluctuation input signal may be determined by the controller depending on the movement input signal. The fluctuation input signal may be determined depending one or more state signals indicative of a state of the hydraulic actuator.

[0009] Typically, if the fluctuation input signal is indicative of a demand to cause a deviation in the movement of the hydraulic actuator during the movement of the hydraulic actuator in accordance with the movement input signal, the control of the hydraulic machine to exchange hydraulic fluid with the hydraulic circuit in accordance with the hydraulic machine control signal may be different than if no demand to cause the deviation in the movement is present.

[0010] The hydraulic machine control signal may be a fluctuating signal. Thus, it may be that the hydraulic machine is controlled to exchange hydraulic fluid with the hydraulic circuit in accordance with the fluctuation input signal.

[0011] The present invention extends to a hydraulic apparatus comprising the controller. The hydraulic apparatus may further comprise: a prime mover; a hydraulic circuit; a hydraulic machine having a rotatable shaft in driven engagement with the prime mover and defining a plurality of working chambers in the hydraulic circuit, each working chamber being defined partially by a movable working surface mechanically coupled to the rotatable shaft, such that, in operation, the hydraulic machine exchanges energy with the hydraulic circuit and the prime mover by movement of the working surfaces and the rotatable shaft; and a hydraulic actuator in the hydraulic circuit.

[0012] The hydraulic machine may exchange energy with the hydraulic circuit by displacing working fluid from at least one of the plurality of working chambers into the hydraulic circuit, or from the hydraulic circuit into at least one of the plurality of working chambers.

[0013] The hydraulic apparatus may include one or more valves in the hydraulic circuit, for controlling routing of hydraulic fluid through the hydraulic circuit. The hydraulic apparatus may include one or more further hydraulic actuators in the hydraulic circuit. The hydraulic apparatus may include one or more further hydraulic machines in the hydraulic circuit.

[0014] The hydraulic apparatus may further comprise a first input interface for receiving a first user input and configured to provide a movement input signal to the controller depending thereon. The movement input signal may be indicative of a demand to move the hydraulic actuator. Thus, an operator can use the first input interface to supply the first user input to request that the hydraulic actuator moves. It will be understood that the fluctuation input signal is typically not determined using the first input interface.

[0015] The hydraulic apparatus may further comprise a second input interface for receiving a second user input and configured to provide a fluctuation input signal to the controller depending thereon. The fluctuation input signal may be indicative of a demand to cause a deviation in the movement of the hydraulic actuator during the movement of the hydraulic actuator in accordance with the movement input signal. Thus, it may be that the operator uses the second input interface to supply the second user input to cause a deviation in the movement of the hydraulic actuator. In particular, the operator can separately supply the first user input and the second user input, with the second user input only being used to cause fluctuation of the movement of the hydraulic actuator.

[0016] The second input interface may be separate from the first input interface. The second input interface may comprise a button. It may be that the second input interface is configured to provide the fluctuation input signal only whilst operated. In other examples, it may be that the second input interface is configured to provide the fluctuation input signal for a pre-determined time from operation of the second input interface. The second input interface may be configured to provide the fluctuation input signal only whilst the first user input is not provided to the first input interface.

[0017] The fluctuation input signal may be indicative of a demand to cause an alternating variation in the movement of the hydraulic actuator. Thus, it may be that at a first time during the movement of the hydraulic actuator in accordance with the movement input signal and the fluctuation input signal, the variation in movement of the hydraulic actuator is in a first sense away from the demanded movement (where that demanded movement may be zero) indicated by the movement input signal, and at a second time during the movement of the hydraulic actuator in accordance with the movement input signal and the fluctuation input signal, the variation in movement of the hydraulic actuator is in a second sense, and said variation may be in position or velocity or acceleration, and is opposite from the first sense, and also away from the demanded movement indicated by the movement in-

put signal. The variation in the movement may alternate between being sometimes in the first sense and sometimes in the second sense. This alternation may be sustained for a significant period of time, such that the hydraulic actuator changes its variation multiple repeated times. In other words, it can be considered that the actuated component of the hydraulic actuator is caused to oscillate or vibrate. This can sometimes be referred to as dither.

[0018] A frequency of the alternating variation may be greater than 0.5 hertz. The frequency may be less than 50 hertz. The frequency may be between 1 and 20 hertz.

[0019] The hydraulic actuator may be a linear actuator. In other examples, the hydraulic actuator may be a rotary actuator, such as a wheel motor.

[0020] As described hereinbefore, the movement input signal may be directly proportional to the first user input received via the first input interface. Alternatively, the movement input signal may be indirectly related to the first user input via another control method such as a pressure control loop. It may be that operation of the first input interface opens a valve, which thus changes the pressure in the system, which causes a change in the pressure control loop, whose output is the movement input signal.

[0021] The hydraulic actuator may have a first actuator chamber fluidly connected to a first working chamber of the hydraulic machine and a second actuator chamber, opposing the first actuator chamber. External hydraulic actuator force arising from supply of pressurised fluid to the first actuator chamber counteracts and is antagonistic to external force arising from pressure in the second actuator chamber. Thus, the hydraulic actuator can be moved in opposite senses depending on the relative pressures of the first actuator chamber and the second actuator chambers.

[0022] It may be that the first working chamber is part of a first group of working chambers, configured to operate as one of a pump and a motor, and that the second actuator chamber is fluidly connected to a second chamber of the hydraulic machine. The second working chamber may be part of a second group of working chambers configured to operate as the other one of a pump and a motor, different to the first group of working chambers.

[0023] The second working chamber may be fluidly connected to a further hydraulic machine. The further hydraulic machine may be a pump, a motor or a pump/motor.

[0024] The second chamber may be fluidly connected to a fluid reservoir via a throttle valve. The fluid reservoir may be a low pressure fluid reservoir, such as an atmospheric pressure fluid reservoir.

[0025] The linear actuator may be a double-acting ram.

[0026] The hydraulic apparatus may be configured to determine the fluctuation input signal depending on determining that the linear actuator is at an end-position of possible movement. Thus, the deviation in the movement of the hydraulic actuator can cause the hydraulic actuator to introduce the deviation movement automatically at the

end-stops of the linear actuator's available range of movement. For example, where the linear actuator is moving a bucket of an excavator, the bucket can be caused to shake to improve emptying of material from the bucket. The hydraulic apparatus may be configured to detect a position of the linear actuator, and to determine the fluctuation input signal depending on the detected position. The position of the linear actuator may be determined by detecting a pressure indicative of the ram being at the end-stop.

[0027] In an example where the hydraulic apparatus is an excavator, a limit switch may be provided associated with the actuator and/or a component connected thereto (such as a bucket). The apparatus may be configured such that when the actuator is at a position indicative of the end of the bucket's travel, the limit switch is actuated, and thereby causes determination of the fluctuation input signal to cause the deviation movement.

[0028] In another example, it may be that when the bucket hits it's end-stop, the load increases, and thus the average pressure (over a period of time e.g. 50ms, or number of samples e.g. 100 samples) in the hydraulic machine is increased. This effect can be used, in a similar way to the limit switch, to cause determination of the fluctuation input signal. Specifically, the increase in pressure can be detected by a pressure sensor (or equivalent means such as using electrical signals generated from a valve solenoid) of the hydraulic apparatus to determine a pressure-related reading for causing determination of the fluctuation input signal when the pressure-related reading satisfies a predetermined threshold.

[0029] The invention may relate particularly to electronically commutated hydraulic machines which intersperse active cycles of working chamber volume, where there is a net displacement of hydraulic working fluid, with inactive cycles of working chamber volume, where there is no net displacement of hydraulic working fluid between the working chamber and the hydraulic circuit, to achieve a demanded fractional displacement. Typically, the majority or all of the active cycles are full stroke cycles, in which the working chambers displace a predetermined maximum displacement of working fluid by suitable control of the timing of valve actuation signals. It is also known to regulate low- and optionally high-pressure valves of one or more of the plurality of working chambers to regulate the fraction of maximum displacement made during an active cycle by operating so-called part stroke cycles.

[0030] The controller may be configured (e.g. programmed) to control the low- and optionally high-pressure valves of the working chambers to cause each working chamber to carry out either an active or an inactive cycle of working chamber volume during each cycle of working chamber volume.

[0031] By 'active cycles' we refer to cycles of working chamber volume which make a net displacement of working fluid. By 'inactive cycles' we refer to cycles of working chamber volume which make no net displacement of

working fluid (typically where one or both of the low-pressure valve and high-pressure valve remain closed throughout the cycle). Typically, active and inactive cycles are interspersed to meet the demand indicated by the demand signal. This contrasts with machines which carry out only active cycles, the displacement of which may be varied.

[0032] The demand signal for one or more working chambers of the hydraulic machine is typically processed as a 'displacement fraction', F_d , being a target fraction of maximum displacement of working hydraulic fluid per rotation of the rotatable shaft. A demand expressed in volumetric terms (volume of working hydraulic fluid per second) can be converted to displacement fraction taking into account the current speed of rotation of the rotatable shaft and the number of working chambers connected in a group to the same high pressure manifold and one or more hydraulic components (e.g. the hydraulic actuator) of the hydraulic apparatus. The demand signal relates to a demand for the combined fluid displacement of the group of one or more working chambers fluidically connected to the said one or more hydraulic components of the hydraulic apparatus via the hydraulic circuit. There may be other groups of one or more working chambers fluidically connected to one or more other hydraulic components having respective demand signals.

[0033] It may be that at least the low-pressure valves (optionally the high-pressure valves, optionally both the low-pressure valves and the high-pressure valves) are electronically controlled valves, and the controller or a further controller is configured to control the (e.g. electronically controlled) valves in phased relationship with cycles of working chamber volume to thereby determine the net displacement of hydraulic fluid by each working chamber on each cycle of working chamber volume. The method may comprise controlling the (e.g. electronically controlled) valves in phased relationship with cycles of working chamber volume to thereby determine the net displacement of hydraulic fluid by each working chamber on each cycle of working chamber volume.

[0034] Groups of one or more working chambers may be dynamically allocated to respective groups of one or more hydraulic components in the hydraulic circuit (e.g. the hydraulic actuator) to thereby change which one or more working chambers are connected to (e.g. a group of) hydraulic components, for example by opening or closing electronically controlled valves (e.g. high-pressure valves and low-pressure valves, described herein), e.g. under the control of a controller. Groups of (e.g. one or more) working chambers may be dynamically allocated to (respective) groups of (e.g. one or more) hydraulic components to thereby change which working chambers of the machine are coupled to which hydraulic components, for example by opening and/or closing (e.g. electronically controlled) valves, e.g. under the control of the or a further controller. The net displacement of hydraulic fluid through each working chamber (and/or each hydraulic component) can be regulated by regulating the net

displacement of the working chamber or chambers which are connected to the hydraulic component or components. Groups of one or more working chambers are typically connected to a respective group of one or more said hydraulic components through a said manifold.

[0035] It may be that the rate of flow of hydraulic fluid accepted by, or output by, each working chamber is independently controllable. It may be that the flow of hydraulic fluid accepted by, or produced by each working chamber can be independently controlled by selecting the net displacement of hydraulic fluid by each working chamber on each cycle of working chamber volume. This selection is typically carried out by the controller.

[0036] Typically, the hydraulic machine is operable as a pump, in a pump operating mode or is operable as a motor in a motor operating mode. It may be that some of the working chambers of the hydraulic machine may pump (and so some working chambers may output hydraulic fluid) while other working chambers of the hydraulic machine may motor (and so some working chambers may input hydraulic fluid).

[0037] In some examples, where a first group of the working chambers are configured to act as a pump, and a second group of the working chambers are configured to act as a motor, it may be that at least one of the first group of working chambers is configured to be connected to a first side of the hydraulic actuator, to supply hydraulic fluid to the first side of the hydraulic actuator. At least one of the second group of working chambers may be configured to be connected to a second side of the hydraulic actuator (e.g. opposite the first side), to receive hydraulic fluid from the second side of the hydraulic actuator. The controller may be configured to cause the supply of hydraulic fluid having a first time-varying fluid flow rate to the first side of the hydraulic actuator, and to cause receipt of hydraulic fluid having a second time-varying fluid flow rate from the second side of the hydraulic actuator. It may be that the first time-varying fluid flow rate is configured to be out of phase with the second time-varying fluid flow rate. Thus, oscillation can be introduced into the movement of the hydraulic actuator. Where at least a portion of the first and second time-varying fluid flow rates can be considered to be sinusoidal, the phase difference may be between 45 degrees and 315 degrees, for example approximately 180 degrees.

[0038] It will be understood that although the first group of working chambers have been described as being configured to function as a pump, and the second group of working chambers have been described as being configured to function as a motor, it may be the other way around, in that the first group of working chambers may be configured to function as the motor and the second group of working chambers may be configured to function as the pump, such that the hydraulic actuator moves in the opposite direction. In some examples, it may even be that both the first group of working chambers and the second group of working chambers are both configured to function as a pump, or separately both configured to

function as a motor. In this case, it may be that there is no net movement of the actuator, but, due to the first and second time-varying fluid flow rates being mutually out of phase, oscillation can be introduced into the movement of the hydraulic actuator.

[0039] The hydraulic machine may be an electronically commutated hydraulic machine, in which the displacement of hydraulic fluid through the working chambers is regulated by electronically controllable valves.

[0040] The hydraulic machine may be a variable displacement hydraulic machine. The hydraulic machine may be a pump. The hydraulic machine may be a motor. The hydraulic machine may be a pump/motor.

[0041] The controller may be configured to determine the hydraulic machine control signal by determining a first signal depending on the fluctuation input signal, and a second signal depending on the movement input signal. The controller may be configured to combine the first signal and the second signal to provide a combined movement input signal, and to determine the hydraulic machine control signal depending on the combined movement input signal. Thus, the movement input signal may be modified based on the fluctuation input signal by combining the first signal with the second signal. In some examples, it may be that the first signal is combined with the second signal by summation.

[0042] The controller may be configured to modify the hydraulic machine control signal to cause resonance in the portion of the hydraulic apparatus moved by the hydraulic actuator (i.e. that is physically connected in some way to the machine in some way). Thus, it will be understood that a resonant frequency of the portion of the hydraulic apparatus movable by the hydraulic actuator may be exploited to cause the fluctuation in the movement of the hydraulic actuator by only a very small fluctuation in the flow rate of hydraulic fluid exchanged between the hydraulic machine and the hydraulic circuit.

[0043] The controller may be configured to determine one or more resonance hydraulic machine control signals known to cause resonance. There will for example be a few of these signals, for each machine speed. Thus, the one or more hydraulic machine control signals that cause resonance of the portion of the hydraulic apparatus moved by the hydraulic actuator can be determined. The controller may be configured to cause movement of the hydraulic actuator at a speed closest to the demanded movement of the hydraulic actuator compared to any other movement of the hydraulic actuator known to cause resonance. To modify the hydraulic machine control signal, the hydraulic machine control signal may be set to the resonance hydraulic machine control signal.

[0044] The controller may be configured to determine a first hydraulic machine control signal. The first hydraulic machine control signal can be used to control the hydraulic machine to cause a first movement of the hydraulic actuator, less than the demanded movement (e.g. position, velocity, or acceleration), and known to cause resonance. The controller may be further configured to de-

termine a second hydraulic machine control signal. The second hydraulic machine control signal can be used to control the hydraulic machine to cause movement of the hydraulic actuator greater than the demanded movement and known to cause resonance. To modify the hydraulic machine control signal, the hydraulic machine control signal may be set to the first hydraulic machine control signal at a first time, changed to the second hydraulic machine control signal at a second time, and further changed back to the first hydraulic machine control signal at a third time. Thus, the hydraulic machine control signal can be dithered between the first hydraulic machine control signal and the second hydraulic machine control signal to cause fluctuation in the movement of the hydraulic actuator relative to the demanded movement. In some examples, it may be that only one of the first and second hydraulic machine control signals are known to cause resonance.

[0045] The controller may modulate the hydraulic machine control signal between the first hydraulic machine control signal and the second hydraulic machine control signal in such a proportion that the hydraulic actuator moves, on average, in accordance with the demand to move the hydraulic actuator. Thus, the hydraulic machine control signal may be set to the first hydraulic machine control signal for a first proportion of time, to cause movement of the hydraulic actuator at a first average rate and to the second hydraulic machine control signal for a second proportion of time, to cause movement of the hydraulic actuator at a second average rate. Typically, the first average rate for the first proportion of time combined with the second average rate for the second proportion of time is equivalent to the rate of the requested movement. In other words, the controller still causes an average movement equivalent to the requested movement.

[0046] The controller may be configured to receive a variation signal indicative of at least one time-varying movement characteristic of one or both of the hydraulic machine and the hydraulic actuator. The hydraulic machine control signal may be determined in further dependence on the variation signal. Thus, the hydraulic machine control signal can be determined taking into account variations and/or instabilities which already exist in the hydraulic machine and/or the hydraulic actuator. It may be that the hydraulic machine control signal is determined so as to reinforce the at least one time-varying characteristic indicated by the variation signal. For example, the variation signal may be combined with the movement input signal. It may be that at least one time-varying component of the variation signal is combined with the movement input signal. The at least one time-varying component of the variation signal may be combined with the movement input signal by summation. It may be that even where a slight phase difference exists between the variation signal and the movement input signal, the two signals can still be combined and will result in increasing the variations in movement caused by the instabilities which already exist in the hydraulic machine and/or the hydraulic actuator. Any phase difference may

be less than 90 degrees, for example less than 45 degrees. In some examples, the variation signal and the movement input signal can be substantially in-phase. Thus, the movements can be reinforced.

[0047] The controller may be configured to determine the time-varying component of the variation signal by applying a high pass filter to the variation signal. It will be understood that the variation signal is indicative of a physical movement characteristic, such as a pressure, a position or a speed of movement of the one or both of the hydraulic machine and the hydraulic actuator. Thus, the low frequency components of the variation signal can be omitted in the time-varying component of the variation signal, leaving only the time varying component thereof. It will be further understood that techniques other than the high-pass filter may be used to obtain a hydraulic machine control signal suitable to exaggerate fluctuation of the movement of the hydraulic actuator and/or the hydraulic machine. For example, it may be that the controller is configured to determine a difference between the variation signal and the demanded movement of the hydraulic actuator, and to determine the fluctuation input signal depending on the determined difference. It may be that the hydraulic machine control signal is determined as the combination of the movement input signal and the determined difference.

[0048] The controller may be configured to restrict at least a portion of the variation signal. Thus, the movements are not reinforced to such an extent that the movement of the hydraulic actuator becomes unwieldy or extreme. It may be that the controller is configured to restrict the portion of the variation signal using dynamic saturation. It may be that the controller is configured to restrict the portion of the variation signal using signal compression.

[0049] The controller may be configured to determine the hydraulic machine control signal depending on receiving a value from a resonance lookup table. Thus, the resonance values can be pre-determined and retrieved when needed. It will be understood that a resonance lookup table is a table of known values of a parameter, the values expected to cause resonance in the portion of the hydraulic apparatus moved by the hydraulic actuator. The controller may be configured to combine the value from the resonance lookup table with the movement input signal to determine the combined movement input signal, and to determine the hydraulic machine control signal depending on the combined movement input signal.

[0050] To populate the values in the lookup table, the controller may be configured to cause movement of the hydraulic actuator in response to a calibration signal, and determine one or more values for the lookup table based on a resultant movement of the hydraulic actuator in response to the calibration signal. Thus, the lookup table can be populated based on movement of the hydraulic actuator during calibration. The controller may be configured to cause movement of the hydraulic actuator in

accordance with a displacement chirp pattern demand in response to the calibration signal. The controller may be configured to demand a step movement of the hydraulic actuator in response to the calibration signal. The resulting movement of the hydraulic actuator may be measured. One or more values to be populated into the lookup table may be determined based on the measured movement of the hydraulic actuator. Thus, oscillation or decay of the movement of the hydraulic actuator can be used to determine the resonant properties of the portion of the hydraulic apparatus moved by the hydraulic actuator. It may be that the values in the lookup table are changed and/or re-populated.

[0051] The movement of the hydraulic actuator in response to the calibration signal may be performed after the movement input signal is received, but before the hydraulic machine is controlled in accordance with the hydraulic machine control signal. Such embodiment is more likely to be of use, and to be acceptable, in an automated system rather than one with hydraulic actuator which is controlled directly by human operator. Thus, the calibration movement of the hydraulic actuator may be performed immediately before the demanded movement of the hydraulic actuator, so that the portion of the hydraulic apparatus moved by the hydraulic actuator has substantially the same physical properties during calibration as during use.

[0052] The movement of the hydraulic actuator in response to the calibration signal may be performed during an idle time of the hydraulic actuator. Thus, no delay is introduced between the operator demanding movement of the hydraulic actuator and the hydraulic actuator's movement in accordance with the demand. The idle time is typically before the movement input signal is received.

[0053] The lookup table may be a multi-dimensional lookup table. Thus, the value may be retrieved from the lookup table depending on multiple variables. The variables may include one or more of a mass of the portion of the hydraulic apparatus moved by the hydraulic actuator (including any load), temperature, pressure, position of actuator, and demanded movement speed.

[0054] The controller may comprise one or more processors and a memory configured to store instructions which when executed by the one or more processors cause the hydraulic apparatus to carry out the functions of the controller described herein. The memory may be non-transitory, computer readable memory. The memory may have the instructions stored thereon. The present invention extends to a non-transitory computer-readable medium (e.g. memory) having the instructions stored thereon to control the apparatus as described herein. The memory may be solid-state memory. The controller may be provided in a single device. In other example, the controller may be distributed, having a plurality of processors. A first processor may be separated from a second processor in a distributed manner.

[0055] The present invention extends to a vehicle comprising the hydraulic apparatus.

[0056] It will be understood that although a controller, hydraulic apparatus and vehicle has been described, the present invention can also be expressed in terms of a method.

[0057] Purely as an example, the present invention extends to a method of controlling a hydraulic machine in a hydraulic circuit with a hydraulic actuator. The hydraulic machine may be as described hereinbefore. The method comprises: receiving a movement input signal indicative of a demand to move the hydraulic actuator; determining a hydraulic machine control signal depending on the movement input signal and a fluctuation input signal; and controlling the hydraulic machine to exchange hydraulic fluid with the hydraulic circuit in accordance with the hydraulic machine control signal to cause movement of the hydraulic actuator in accordance with the movement input signal and the fluctuation input signal.

[0058] It will be understood that the method may also include any of the steps performed by the controller as elsewhere described herein.

Description of the Drawings

[0059] An example embodiment of the present invention will now be illustrated with reference to the following Figures in which:

Figure 1 is a schematic illustration of an example of hydraulic apparatus as described herein;

Figure 2 is a schematic illustration of an example of hydraulic apparatus as described herein;

Figure 3 is a schematic illustration of systems of a vehicle according to an example of the present disclosure;

Figure 4 is a flowchart illustrating a method of controlling a hydraulic machine as described herein; and

Figure 5 is a schematic diagram of an example of a hydraulic machine.

Detailed Description of an Example Embodiment

[0060] Figure 1 is a schematic illustration of an example of hydraulic apparatus as described herein. The hydraulic apparatus 100 comprises a hydraulic machine 110 in a hydraulic circuit 120. A hydraulic actuator 130 is fluidly connected to the hydraulic machine 110 via the hydraulic circuit 120. In this example, the hydraulic apparatus is part of an excavator, including a bucket 140 which can be pivoted by operation of the hydraulic actuator 130.

[0061] The hydraulic apparatus 100 further comprises a controller 150 for controlling the operation of the hydraulic machine 110 to thereby cause movement of the bucket 140 mechanically connected to the hydraulic actuator 130.

[0062] The hydraulic apparatus 100 also comprises a first input interface 160 in the form of a joystick control 160 and a second input interface 170 in the form of a

pushbutton 170, provided on an end of the joystick control 160.

[0063] The controller 150 is configured to receive a movement input signal 165 from operation of the joystick control 160, and a fluctuation input signal 175 caused by operation of the pushbutton 170. In this example, the fluctuation input signal 175 is in the form of a sinusoidally varying alternating signal 175. The controller 150 is configured to determine a hydraulic machine control signal 115 by combining the movement input signal 165 with the fluctuation input signal 175, in this instance by summing the movement input signal 165 and the fluctuation input signal 175. The hydraulic machine control signal 115 is used to control the hydraulic machine 110 to exchange energy in the form of hydraulic fluid with the hydraulic circuit 120 at a flow rate indicated by the hydraulic machine control signal 115.

[0064] In this example, the hydraulic machine 110 is a pump/motor 110, as described further with reference to Figure 5 hereinafter.

[0065] When the pushbutton 170 is not operated, the hydraulic machine control signal 115 will cause the hydraulic machine 110 to exchange hydraulic fluid with the hydraulic circuit 120 at a substantially steady flow-rate, determined by the position of the joystick control 160. When the joystick control 160 is moved in a first direction (e.g. backwards), the hydraulic machine 110 is controlled to operate as a pump and to pump hydraulic fluid into the hydraulic circuit 120, towards the hydraulic actuator 130, to cause retraction of the ram of the hydraulic actuator 130. When the joystick control 160 is moved in a second direction, opposite the first direction, (e.g. forwards), the hydraulic machine 110 is controlled to operate as a motor and to draw hydraulic fluid from the hydraulic circuit 120 through the hydraulic machine 110, away from the hydraulic actuator 130, to cause extension of the ram of the hydraulic actuator 130. In another embodiment, the hydraulic machine 110 is controlled to operate as a pump to supply pressurised fluid to the hydraulic actuator, to cause respective extension. The opposite actuator motion may be realised by a simple cross-over spool valve, located upstream, to pressurise the opposing piston face.

[0066] When the pushbutton 170 is operated, the overall movement directions of the hydraulic actuator 130 remain consistent with the situation where the pushbutton 170 is not operated, as described above, with the hereinafter described differences. The operation of the pushbutton 170 results in the generation of the fluctuation input signal 175, illustrated as a sinusoidally varying signal 175 in Figure 1. As a result, the hydraulic machine control signal 115 also includes a fluctuation component, causing the hydraulic machine 110 to exchange hydraulic fluid with the hydraulic circuit 120 at a cyclically-varying flow rate. The frequency of variation in the flow rate is the same as the frequency of the variation signal 175. Accordingly, whilst the direction of overall movement of the hydraulic actuator 130 will still correspond to the movement input signal 165, the cyclically-varying flow rate

causes a cyclically-varying dither in the movement of the hydraulic actuator 130, and therefore in the movement of the bucket 140. When the pushbutton 170 is operated, but the joystick control 160 is not operated (e.g. where no input is provided to the joystick control 160), a fluctuation input signal 175 is generated but the movement input signal will be zero, resulting in no net movement of the actuator, but a relatively small oscillating movement of the actuator.

[0067] Figure 2 is a schematic illustration of an example of hydraulic apparatus as described herein. The hydraulic apparatus 200 functions similarly to the hydraulic apparatus 100 described with reference to Figure 1, though only the hydraulic actuator 230 and hydraulic machines 210a, 210b, are shown.

[0068] The hydraulic actuator 230 is in the form of a double-acting ram 230 having a movable rod 236, a first actuator chamber 232 and a second actuator chamber 234. The first actuator chamber 232 is fluidly connected to a first hydraulic machine 210a, in the form of a motor 210a, via a hydraulic circuit first portion 222. The motor 210a is configured to extract hydraulic fluid from the hydraulic circuit first portion 222. The second actuator chamber 234 is fluidly connected to a second hydraulic machine 210b, in the form of a pump 210b, via a hydraulic circuit second portion 224. The pump 210b is configured to supply hydraulic fluid to the hydraulic fluid second portion 224.

[0069] Although the hydraulic machines 210a, 210b have been described separately, it will be understood that each may be a separate hydraulic machine 210a, 210b, such as two pump/motors, or each may represent a different groups of working chambers of the same pump/motor, such that the first hydraulic machine 210a is provided by a first group of working chambers of a hydraulic machine and the second hydraulic machine 210b is provided by a second group of working chambers of the same hydraulic machine.

[0070] If the hydraulic apparatus 200 is operated in the configuration shown in Figure 2, with the first hydraulic machine 210a in the form of a motor 210a and the second hydraulic machine 210b in the form of a pump 210b, it will be understood that the rod 236 will be retracted due to a reduction in the volume of the first actuator chamber 232, and an expansion in the volume of the second actuator chamber 234. To cause fluctuation in the movement of the hydraulic actuator 230, it may be that a first periodically-varying flowrate is caused by the first hydraulic machine 210a, and a second periodically-varying flowrate is caused by the second hydraulic machine 210b. The first periodically-varying flowrate is in the opposite sense, of differing average flowrate and phase-shifted with respect to the second periodically-varying flowrate, to enhance the vibration of the movement of the rod 236. It may be that both sides act as pumps, but with differing average flowrates and/or phases, in such a way that either there is no net movement of the actuator, or that there is a net movement, due to the difference in the

average flowrates of each side of the actuator.

[0071] Figure 3 is a schematic illustration of systems of a vehicle according to an example of the present disclosure. The vehicle 300 comprises hydraulic apparatus 310 as described herein, such as in the form of a hydraulic machine 310, and a controller 320. The controller 320 is configured to exchange signals 325 with the hydraulic apparatus 310 to control the hydraulic apparatus 310 in accordance with input signals received by the controller 320, for example from user inputs by an operator of the vehicle 300. The controller 320 in this example is realised by one or more processors 330 and a computer-readable memory 340. The memory 340 stores instructions which, when executed by the one or more processors 330, cause the hydraulic apparatus 310 to operate as described herein.

[0072] Although the controller 320 is shown as being part of the vehicle 300, it will be understood that one or more components of the controller 320, or even the whole controller 320 can be provided separate from the vehicle 300, for example remotely from the vehicle 300, to exchange signals with the vehicle 300 by wireless communication.

[0073] Figure 4 is a flowchart illustrating a method of controlling a hydraulic machine as described herein. The method 400 comprises determining a hydraulic machine control signal depending on a movement input signal and a fluctuation input signal, and controlling a hydraulic machine in accordance with the hydraulic machine control signal.

[0074] Specifically, the method 400 comprises receiving 410 a demand to move the hydraulic actuator. A movement input signal is indicative of the demand to move the hydraulic actuator.

[0075] The method 400 further comprises determining 420 a hydraulic machine control signal depending on the movement input signal and a fluctuation input signal.

[0076] The method 400 further comprises controlling 430 the hydraulic machine to exchange hydraulic fluid with the hydraulic circuit in accordance with the hydraulic machine control signal. Thus, the hydraulic actuator is caused to move in accordance with the movement input signal and the fluctuation input signal.

[0077] Figure 5 is a schematic diagram of part of the hydraulic apparatus shown in Figures 1a and 1b, and shows a single group of working chambers currently connected to one or more hydraulic components (e.g. an actuator) through a high pressure manifold 554. Figure 5 provides detail on the first group 500, said group comprises a plurality of working chambers (8 are shown) having cylinders 524 which have working volumes 526 defined by the interior surfaces of the cylinders and pistons 528 (providing working surfaces 528) which are driven from a rotatable shaft 530 by an eccentric cam 532 and which reciprocate within the cylinders to cyclically vary the working volume of the cylinders. The rotatable shaft is firmly connected to and rotates with a drive shaft. A shaft position and speed sensor 534 sends electrical sig-

nals through a signal line 536 to a controller 550, which thus enables the controller to determine the instantaneous angular position and speed of rotation of the shaft, and to determine the instantaneous phase of the cycles of each cylinder.

[0078] The working chambers are each associated with Low Pressure Valves (LPVs) in the form of electronically actuated face-sealing poppet valves 552, which have an associated working chamber and are operable to selectively seal off a channel extending from the working chamber to a low-pressure hydraulic fluid manifold 554, which may connect one or several working chambers, or indeed all as is shown here, to the low-pressure hydraulic fluid manifold hydraulic circuit. The LPVs are normally open solenoid actuated valves which open passively when the pressure within the working chamber is less than or equal to the pressure within the low-pressure hydraulic fluid manifold, i.e. during an intake stroke, to bring the working chamber into fluid communication with the low-pressure hydraulic fluid manifold but are selectively closable under the active control of the controller via LPV control lines 556 to bring the working chamber out of fluid communication with the low-pressure hydraulic fluid manifold. The valves may alternatively be normally closed valves. As well as force arising from the pressure difference across the valve, flow forces from the passage of fluid across the valve, also influence the net force on the moving valve member.

[0079] The working chambers are each further associated with a respective High-Pressure Valve (HPV) 564 each in the form of a pressure actuated delivery valve. The HPVs open outwards from their respective working chambers and are each operable to seal off a respective channel extending from the working chamber through a valve block to a high-pressure hydraulic fluid manifold 558, which may connect one or several working chambers, or indeed all as is shown in Figure 5. The HPVs function as normally-closed pressure-opening check valves which open passively when the pressure within the working chamber exceeds the pressure within the high-pressure hydraulic fluid manifold. The HPVs also function as normally-closed solenoid actuated check valves which the controller may selectively hold open via HPV control lines 562 once that HPV is opened by pressure within the associated working chamber. Typically, the HPV is not openable by the controller against pressure in the high-pressure hydraulic fluid manifold. The HPV may additionally be openable under the control of the controller when there is pressure in the high-pressure hydraulic fluid manifold but not in the working chamber, or may be partially openable.

[0080] In a pumping mode, the controller selects the net rate of displacement of hydraulic fluid from the working chamber to the high-pressure hydraulic fluid manifold by the hydraulic motor by actively closing one or more of the LPVs typically near the point of maximum volume in the associated working chamber's cycle, closing the path to the low-pressure hydraulic fluid manifold and thereby

directing hydraulic fluid out through the associated HPV on the subsequent contraction stroke (but does not actively hold open the HPV). The controller selects the number and sequence of LPV closures and HPV openings to produce a flow or create a shaft torque or power to satisfy a selected net rate of displacement.

[0081] In a motoring mode of operation, the controller selects the net rate of displacement of hydraulic fluid, displaced via the high-pressure hydraulic fluid manifold, actively closing one or more of the LPVs shortly before the point of minimum volume in the associated working chamber's cycle, closing the path to the low-pressure hydraulic fluid manifold which causes the hydraulic fluid in the working chamber to be compressed by the remainder of the contraction stroke. The associated HPV opens when the pressure across it equalises and a small amount of hydraulic fluid is directed out through the associated HPV, which is held open by the controller. The controller then actively holds open the associated HPV, typically until near the maximum volume in the associated working chamber's cycle, admitting hydraulic fluid from the high-pressure hydraulic fluid manifold to the working chamber and applying a torque to the rotatable shaft.

[0082] As well as determining whether or not to close or hold open the LPVs on a cycle by cycle basis, the controller is operable to vary the precise phasing of the closure of the HPVs with respect to the varying working chamber volume and thereby to select the net rate of displacement of hydraulic fluid from the high-pressure to the low-pressure hydraulic fluid manifold or vice versa.

[0083] Arrows on the low pressure fluid connection 506, and the high-pressure fluid connection 521 indicate hydraulic fluid flow in the motoring mode; in the pumping mode the flow is reversed. A pressure relief valve 566 may protect the first group from damage.

[0084] In normal operation, the active and inactive cycles of working chamber volume are interspersed to meet the demand indicated by the hydraulic machine control signal.

[0085] In summary, there is provided a controller (320) for a hydraulic machine (310), the hydraulic machine (310) in a hydraulic circuit including a hydraulic actuator, having a rotatable shaft in driven engagement with a prime mover, and defining a plurality of working chambers in the hydraulic circuit, each working chamber being defined partially by a movable working surface mechanically coupled to the rotatable shaft, such that, in operation, the hydraulic machine (310) exchanges energy with the hydraulic circuit and the prime mover by movement of the working surfaces and the rotatable shaft. The controller (320) is configured to: receive a movement input signal indicative of a demand to move the hydraulic actuator; determine a hydraulic machine control signal depending on the movement input signal and a fluctuation input signal; and control the hydraulic machine (310) to exchange hydraulic fluid with the hydraulic circuit in accordance with the hydraulic machine control signal to cause movement of the hydraulic actuator in accordance

with the movement input signal and the fluctuation input signal.

[0086] Throughout the description and claims of this specification, the words "comprise" and "contain" and variations of them mean "including but not limited to", and they are not intended to and do not exclude other components, integers or steps. Throughout the description and claims of this specification, the singular encompasses the plural unless the context otherwise requires. In particular, where the indefinite article is used, the specification is to be understood as contemplating plurality as well as singularity, unless the context requires otherwise.

[0087] Features, integers, characteristics or groups described in conjunction with a particular aspect, embodiment or example of the invention are to be understood to be applicable to any other aspect, embodiment or example described herein unless incompatible therewith. All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive. The invention is not restricted to the details of any foregoing embodiments. The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

Claims

1. A controller for a hydraulic machine, the hydraulic machine in a hydraulic circuit including a hydraulic actuator, having a rotatable shaft in driven engagement with a prime mover, and defining a plurality of working chambers in the hydraulic circuit, each working chamber being defined partially by a movable working surface mechanically coupled to the rotatable shaft, such that, in operation, the hydraulic machine exchanges energy with the hydraulic circuit and the prime mover by movement of the working surfaces and the rotatable shaft, wherein the controller is configured to:

receive a movement input signal indicative of a demand to move the hydraulic actuator;
determine a hydraulic machine control signal depending on the movement input signal and a fluctuation input signal; and
control the hydraulic machine to exchange hydraulic fluid with the hydraulic circuit in accordance with the hydraulic machine control signal to cause movement of the hydraulic actuator in accordance with the movement input signal and the fluctuation input signal.

2. The controller as claimed in claim 1, wherein the controller is configured to receive the fluctuation input signal.
3. A hydraulic apparatus comprising:
 - a prime mover;
 - a hydraulic circuit;
 - a hydraulic machine having a rotatable shaft in driven engagement with the prime mover and defining a plurality of working chambers in the hydraulic circuit, each working chamber being defined partially by a movable working surface mechanically coupled to the rotatable shaft, such that, in operation, the hydraulic machine exchanges energy with the hydraulic circuit and the prime mover by movement of the working surfaces and the rotatable shaft;
 - a hydraulic actuator in the hydraulic circuit; and
 - a controller as claimed in any preceding claim.
4. The hydraulic apparatus as claimed in claim 3, further comprising a first input interface for receiving a first user input and configured to provide a movement input signal to the controller depending thereon, the movement input signal indicative of a demand to move the hydraulic actuator.
5. The hydraulic apparatus as claimed in claim 4, further comprising a second input interface for receiving a second user input and configured to provide a fluctuation input signal to the controller depending thereon, the fluctuation input signal indicative of a demand to cause a controlled deviation in the movement of the hydraulic actuator during the movement of the hydraulic actuator in accordance with the movement input signal.
6. The controller or the hydraulic apparatus of any preceding claim, wherein the fluctuation input signal is indicative of a demand to cause an alternating variation in the movement of the hydraulic actuator, optionally wherein a frequency of the alternating variation is between 1 and 20 hertz.
7. The controller or the hydraulic apparatus of any preceding claim, wherein the hydraulic actuator is a linear actuator comprising a double-acting ram, the double-acting ram having a first actuator chamber fluidly connected to a first working chamber of the hydraulic machine and a second actuator chamber, opposing the first actuator chamber, where the pressure in the first actuator chamber provides a ram force in opposition to the second actuator chamber, optionally wherein the hydraulic apparatus is configured to determine the fluctuation input signal depending on determining that the linear actuator is at an end-position of possible movement.
8. The controller or the hydraulic apparatus of any preceding claim, wherein the hydraulic machine is an electronically commutated hydraulic machine, in which the displacement of hydraulic fluid through the working chambers is regulated by electronically controllable valves.
9. The controller or the hydraulic apparatus of any preceding claim, wherein the controller is configured to determine the hydraulic machine control signal by determining a first signal depending on the fluctuation input signal, and a second signal depending on the movement input signal, to combine the first signal and the second signal to provide a combined movement input signal, and to determine the hydraulic machine control signal depending on the combined movement input signal.
10. The controller or the hydraulic apparatus of any preceding claim, wherein the controller is configured to modify the hydraulic machine control signal to cause resonance in a portion of the hydraulic apparatus moved by the hydraulic actuator.
11. The controller or the hydraulic apparatus of claim 10, wherein the controller is configured to determine a resonance hydraulic machine control signal known to cause resonance and to cause movement of the hydraulic actuator closest to the demanded movement of the hydraulic actuator compared to any other movement of the hydraulic actuator known to cause resonance, and wherein, to modify the hydraulic machine control signal, the hydraulic machine control signal is set to the resonance hydraulic machine control signal, or
 - wherein the controller is configured to determine a first hydraulic machine control signal to cause a first movement of the hydraulic actuator less than the demanded movement, and to determine a second hydraulic machine control signal to cause movement of the hydraulic actuator greater than the demanded movement and, and wherein to modify the hydraulic machine control signal, the hydraulic machine control signal is set to the first hydraulic machine control signal at a first time, changed to the second hydraulic machine control signal at a second time, and further changed back to the first hydraulic machine control signal at a third time, wherein at least one of the first and second hydraulic machine control signals is one that is known to cause resonance, optionally
 - wherein the controller modulates the hydraulic machine control signal between the first hydraulic machine control signal and the second hydraulic machine control signal in such a proportion that the hydraulic actuator moves, on aver-

age, in accordance with the demand to move the hydraulic actuator.

12. The controller or the apparatus of any preceding claim, wherein the controller is configured to receive a variation signal indicative of at least one time-varying movement characteristic of one or both of the hydraulic machine and the hydraulic actuator, and wherein the hydraulic machine control signal is determined in further dependence on the variation signal, optionally wherein the controller is configured to restrict at least a portion of the variation signal. 5 10
13. The controller or the apparatus of any of claims 10 to 12, wherein the controller is configured to determine the hydraulic machine control signal depending on receiving a value from a resonance lookup table, optionally wherein the lookup table is a multi-dimensional lookup table. 15 20
14. The controller or the apparatus of claim 13, wherein, to populate the values in the lookup table, the controller is configured to cause movement of the hydraulic actuator in response to a calibration signal, and determine one or more values for the lookup table based on a resultant movement of the hydraulic actuator in response to the calibration signal, optionally 25 30
- wherein the movement of the hydraulic actuator in response to the calibration signal is performed after the movement input signal is received, but before the hydraulic machine is controlled in accordance with the hydraulic machine control signal, or optionally 35 40
- wherein the movement of the hydraulic actuator in response to the calibration signal is performed during an idle time of the hydraulic actuator, the idle time being when no demand to move the hydraulic actuator is made.
15. A vehicle comprising the hydraulic apparatus of any of claims 3 to 14. 45

50

55

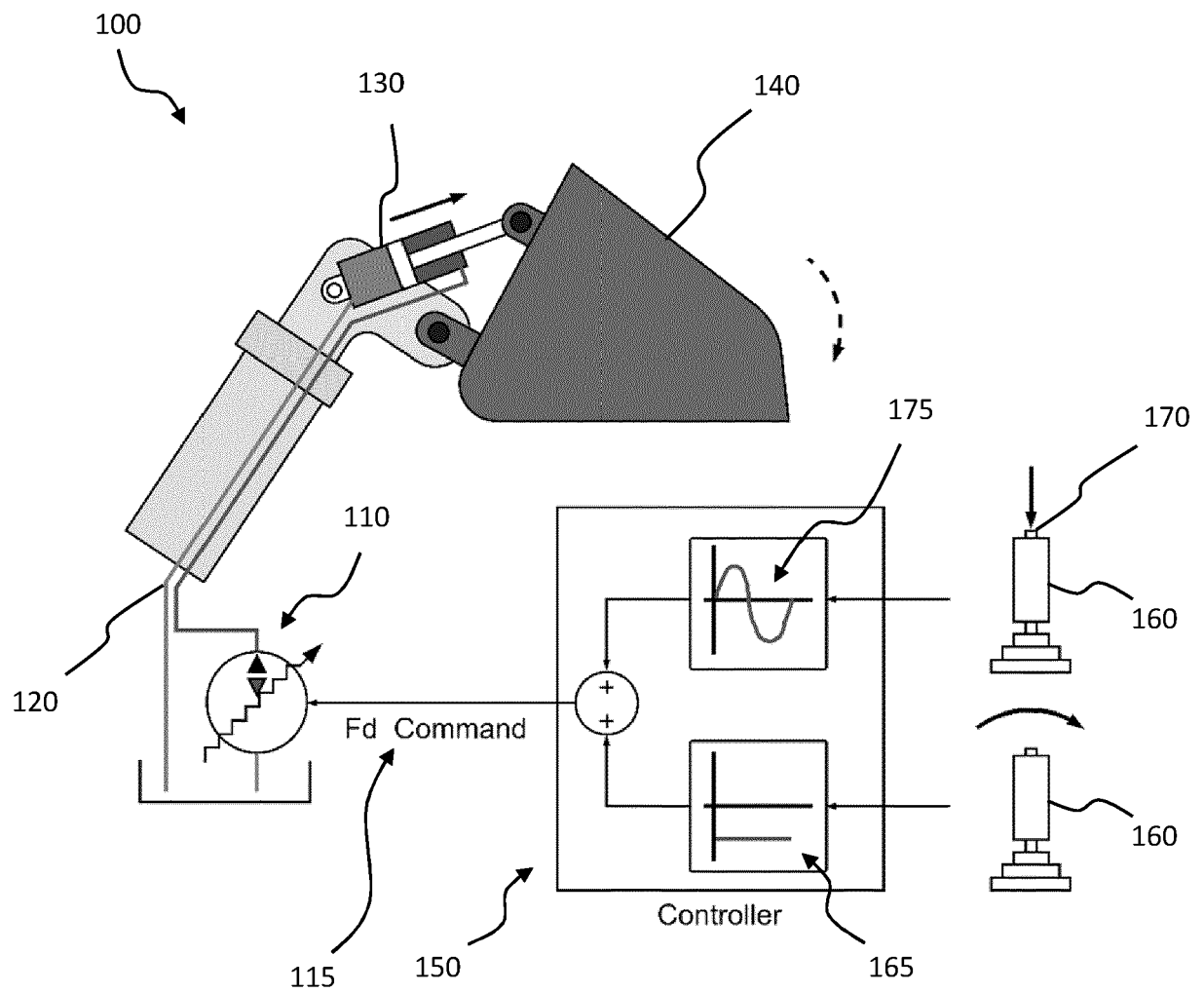
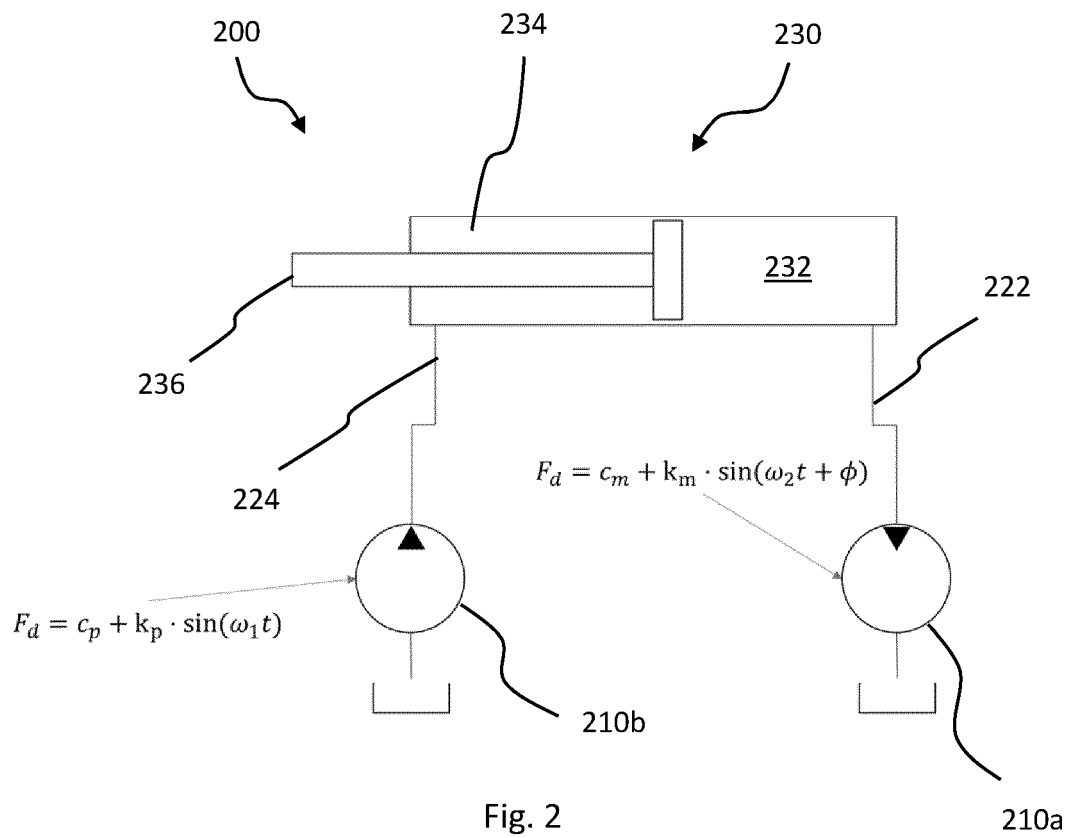


Fig. 1



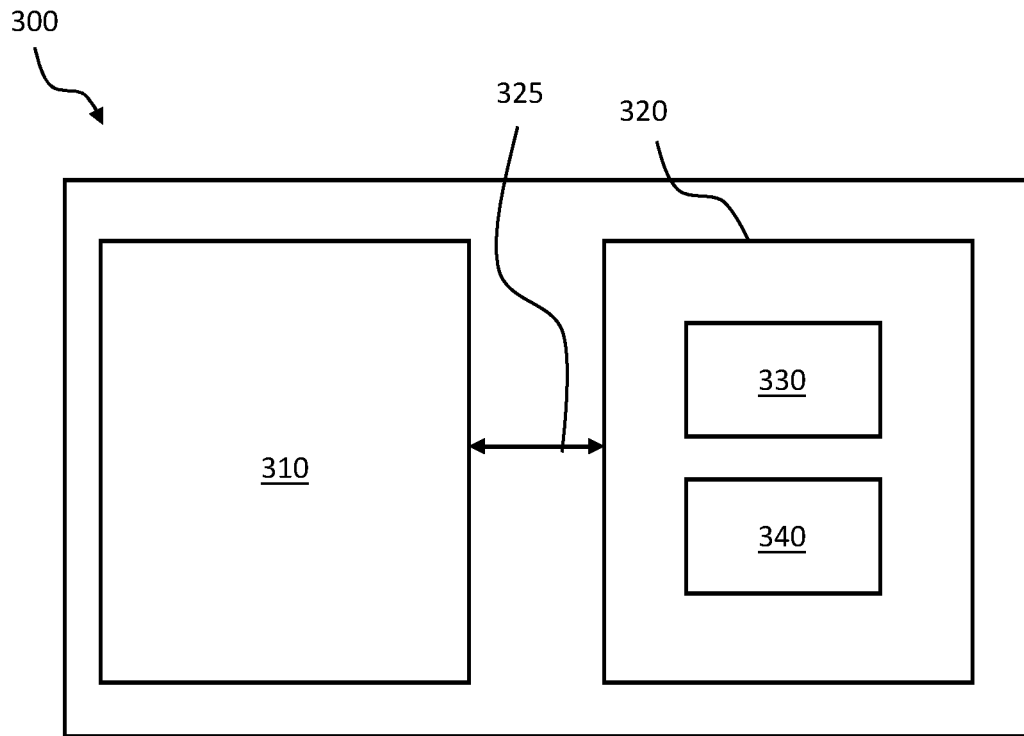


Fig. 3

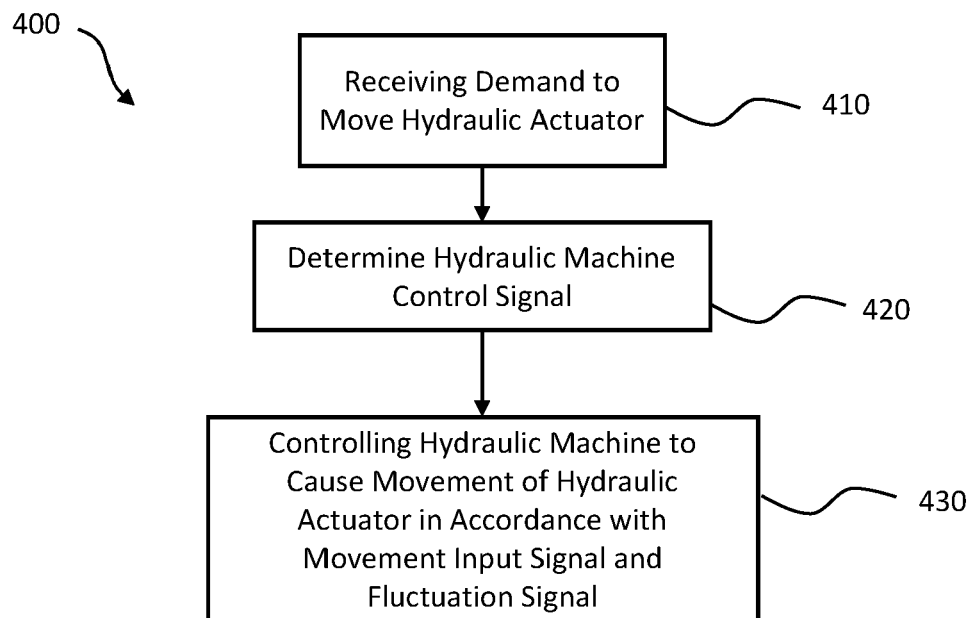


Fig. 4

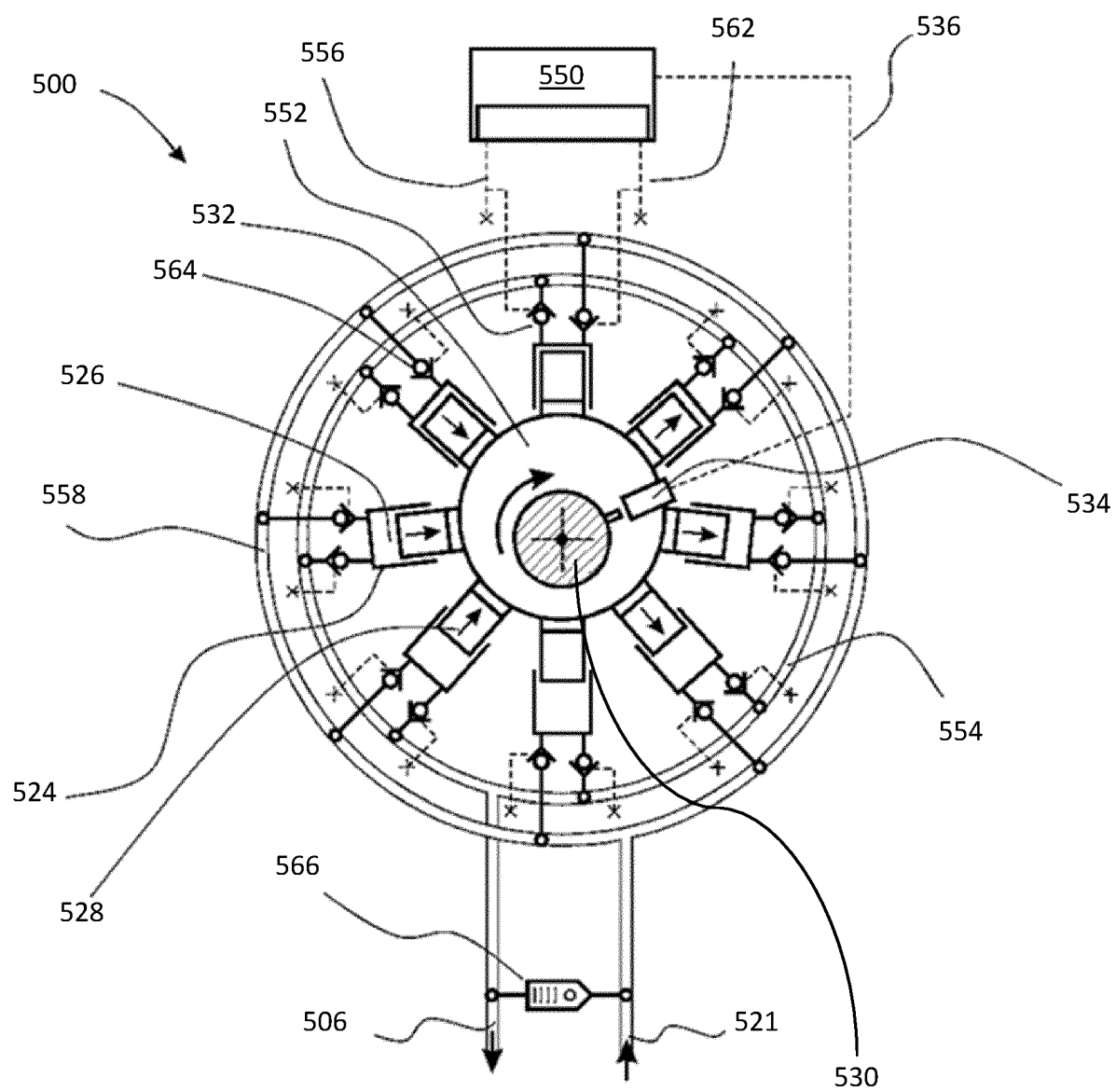


Fig. 5



EUROPEAN SEARCH REPORT

Application Number

EP 21 18 7784

5

10

15

20

25

30

35

40

45

50

55

1

EPO FORM 1503 03.82 (P04C01)

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2009/056322 A1 (BRINKMAN JASON L [US] ET AL) 5 March 2009 (2009-03-05)	1, 2	INV. E02F9/22 F04B49/06 F15B21/08
Y	* paragraphs [0019], [0034]; figure 2 * -----	3-8, 15	
X	JP H08 165678 A (YANMAR DIESEL ENGINE CO) 25 June 1996 (1996-06-25) * abstract; figure 1 * -----	1	
X	WO 2016/180686 A1 (CATERPILLAR SARL [CH]) 17 November 2016 (2016-11-17) * paragraph [0018]; figure 1 * -----	1	
X	US 2004/176894 A1 (ALEXADER WILLIAM GUY [US] ET AL) 9 September 2004 (2004-09-09) * paragraph [0012]; figure 1 * -----	1	
Y	EP 3 620 583 A1 (ARTEMIS INTELLIGENT POWER LTD [GB]) 11 March 2020 (2020-03-11) * paragraph [0150] - paragraph [0152]; figures 1, 2, 7 * -----	3-8, 15	
Y	US 2019/093310 A1 (KENKEL AARON R [US] ET AL) 28 March 2019 (2019-03-28) * paragraph [0021]; figure 2 * -----	6	TECHNICAL FIELDS SEARCHED (IPC)
A	US 2018/180067 A1 (STAVROU PAUL C [US]) 28 June 2018 (2018-06-28) * paragraphs [0017], [0029] * -----	1, 3, 15	E02F F04B F15B F15D
A	US 5 287 699 A (TAKAMURA FUJITOSHI [JP] ET AL) 22 February 1994 (1994-02-22) * column 3, line 10 - line 14 * -----	6	
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 3 January 2022	Examiner Papadimitriou, S
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 21 18 7784

5

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

03-01-2022

10

15

20

25

30

35

40

45

50

55

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2009056322 A1	05-03-2009	NONE	
JP H08165678 A	25-06-1996	JP 3537520 B2	14-06-2004
		JP H08165678 A	25-06-1996
WO 2016180686 A1	17-11-2016	CN 107636235 A	26-01-2018
		DE 112016001689 T5	21-12-2017
		JP 6604624 B2	13-11-2019
		JP 2016211256 A	15-12-2016
		US 2018135274 A1	17-05-2018
		WO 2016180686 A1	17-11-2016
US 2004176894 A1	09-09-2004	AR 043408 A1	27-07-2005
		AT 334315 T	15-08-2006
		AU 2004217795 A1	16-09-2004
		BR PI0407859 A	01-03-2006
		CA 2518007 A1	16-09-2004
		DE 602004001678 T2	30-11-2006
		DK 1604118 T3	27-11-2006
		EP 1604118 A1	14-12-2005
		JP 2006519965 A	31-08-2006
		KR 20050106087 A	08-11-2005
		US 2004176894 A1	09-09-2004
		WO 2004079206 A1	16-09-2004
		ZA 200504989 B	27-09-2006
EP 3620583 A1	11-03-2020	CN 110886731 A	17-03-2020
		EP 3620583 A1	11-03-2020
		JP 2020041700 A	19-03-2020
		US 2020080551 A1	12-03-2020
US 2019093310 A1	28-03-2019	BR 102018069575 A2	30-07-2019
		US 2019093310 A1	28-03-2019
US 2018180067 A1	28-06-2018	DE 102017221881 A1	28-06-2018
		US 2018180067 A1	28-06-2018
US 5287699 A	22-02-1994	NONE	