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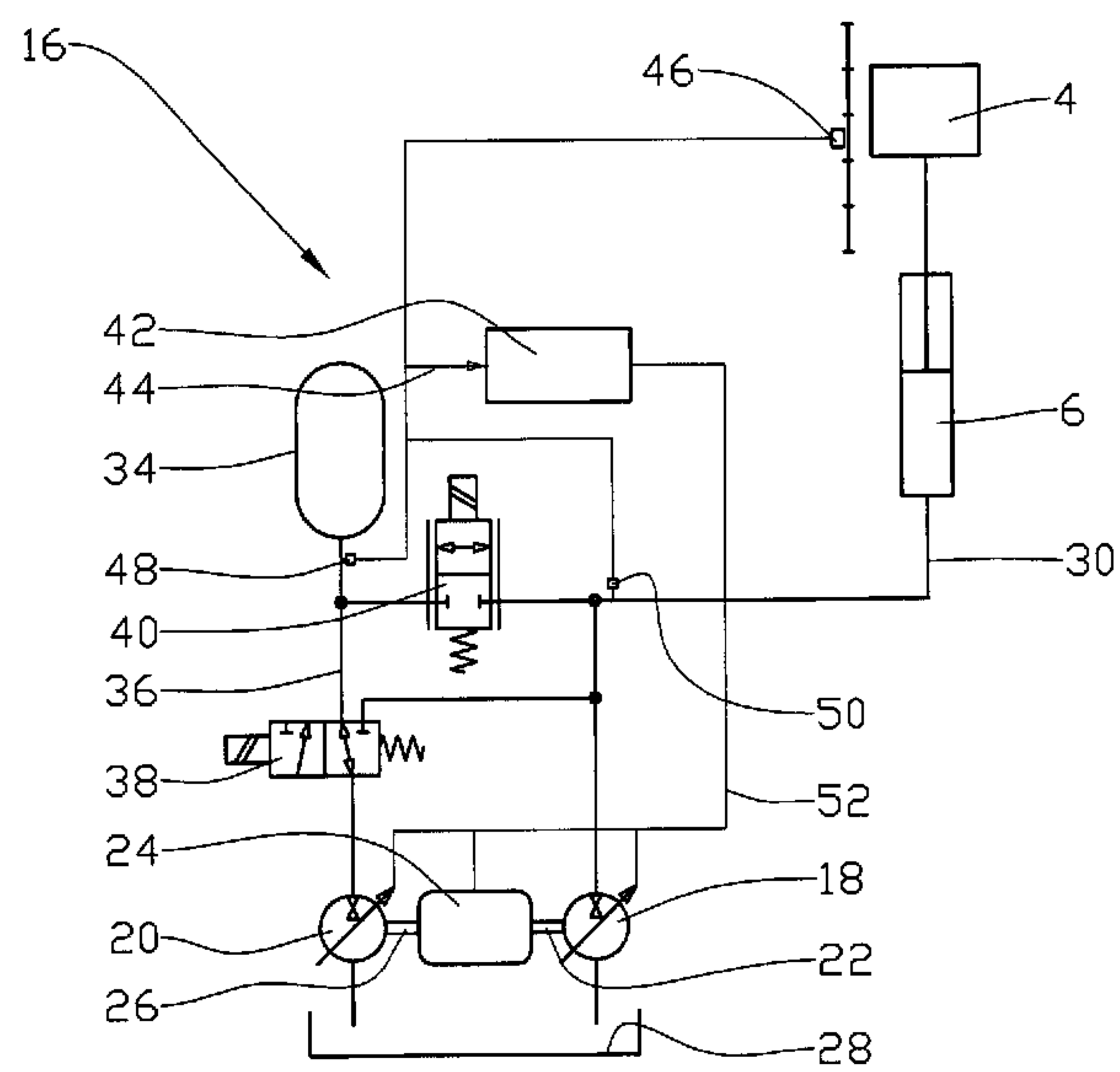

Fig. 3

(57) **Abrégé/Abstract:**
An apparatus (16) and method for recuperation of hydraulic energy from an actuator (6) where a first drive (22) of a first hydraulic machine (18) and a second drive (26) of a second hydraulic machine (20) are mechanically connected, and where the first hydraulic machine (18) is in hydraulic communication with an actuator (6), and where the second hydraulic machine (20) is in hydraulic communication with an accumulator (34).

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(54) **Title**: AN APPARATUS AND METHOD FOR RECUPERATION OF HYDRAULIC ENERGY

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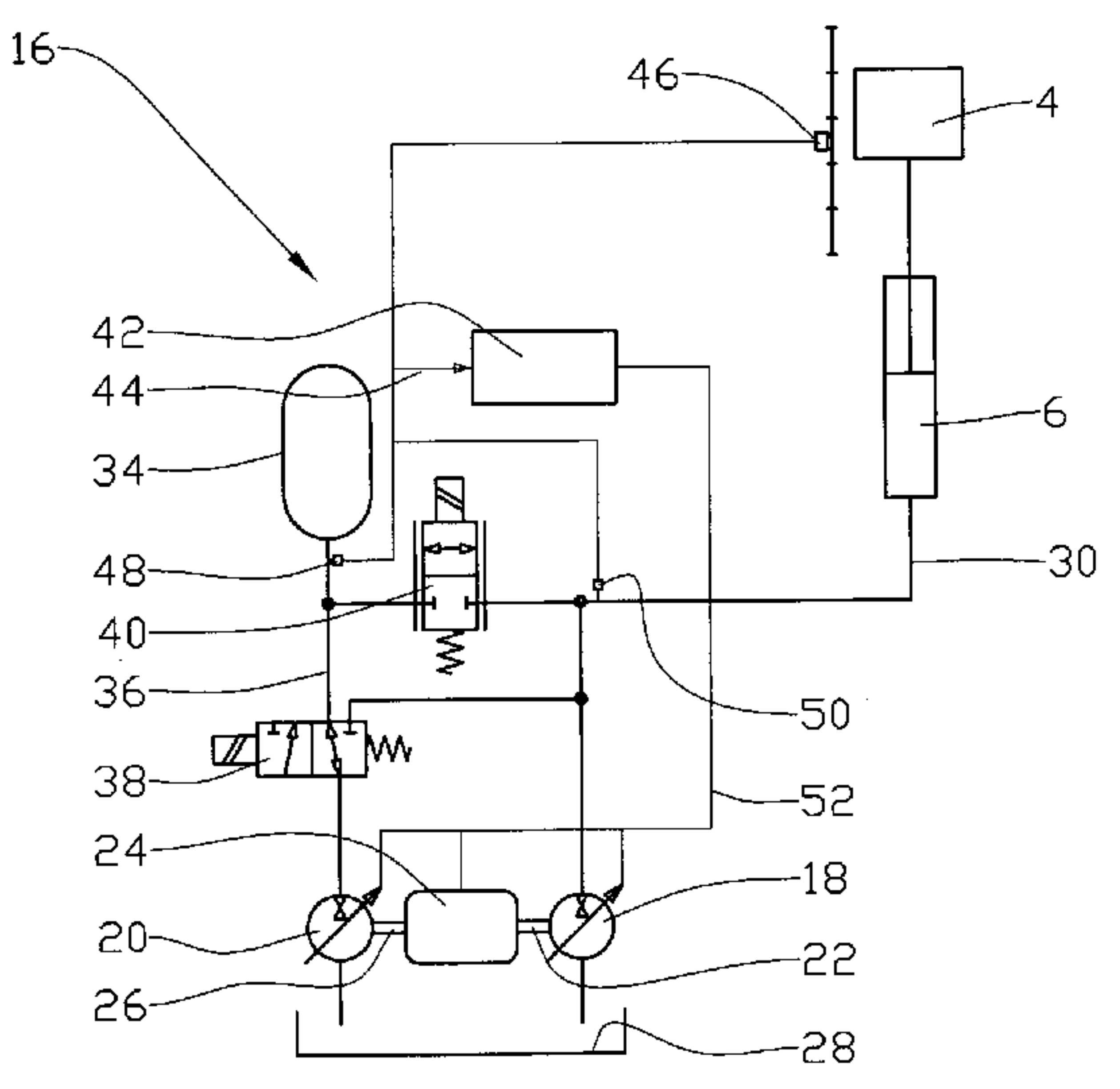

Fig. 3

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AN APPARATUS AND METHOD FOR RECUPERATION OF HYDRAULIC ENERGY

There is provided an apparatus for recuperation of hydraulic energy. More precisely, there is provided an apparatus for recuperation of hydraulic energy, typically from an actuator, typically a hoist, where a first drive of a first hydraulic machine and a second drive of a second hydraulic machine are mechanically connected, and where the first hydraulic machine is in hydraulic communication with an actuator. The invention also includes a method for operation of the apparatus.

Hydraulic hoisting systems are included in an array of equipment such as offshore and land based drilling rigs, winches and equipment. The hoisting systems are regarded the backbone of a rig in terms of handling a drill as well as controlling a drilling process as such.

Several of these applications exhibit a cyclic load profile where a load is repeatedly lifted and lowered. At least in some of the prior art hoisting systems potential energy is dissipated as heat during lowering of the load.

Such systems are characterized by a large variation in operational envelope in terms of hook load and lifting speed, as well as duration of a particular operation. The hoisting system is thus dimensioned in order to fulfill the maximum power requirements given by a certain operation. Therefore, the hydraulic power unit of a typical hoisting system consists of several hydraulic machines.

It is known to recuperate at least some of such potential energy by utilization of a hydraulic transformer. US 3,627,451 discloses a hydraulic transfer unit for transferring hydraulic power at the same pressures and in either direction between two separate and isolated hydraulic control systems.

US 7,249,457 discloses a hydraulic system that has gravitational load energy recuperation by opening a recuperation piloted valve with a pilot pressure supplied by a hydraulic pump so as to drive a recuperation hydraulic motor with a source of fluid pressurized by gravity from the load. The recuperation hydraulic motor drives the mechanical drive train of a prime mover that drives the pump that supplies the load, and other pumps that supply other loads.

The purpose of the invention is to overcome or reduce at least one of the disadvantages of the prior art.

The purpose is achieved according to the invention by the features as disclosed in the description below and in the following patent claims.

There is provided an apparatus for recuperation of hydraulic energy from a actuator, typically a hoist, where a first drive of a first hydraulic machine and a second drive of a second hydraulic machine are mechanically connected, and where the first hydraulic machine is in hydraulic communication with an actuator, wherein the second hydraulic machine is in hydraulic communication with an accumulator.

At least the first or second hydraulic machine is here typically a machine that is designed to operate as a variable displacement pump and motor, for example an over-centre type pump/motor. The term "displacement" is taken to mean displacement per revolution of the pump/motor.

The actuator may take the form of a hydraulic ram, a hydraulic pump/motor or any other suitable hydraulic equipment capable of lifting a load directly or via machine elements such as a gear, a rope or a pulley.

The accumulator may be a gas/liquid type of accumulator where a gas, typically nitrogen, is compressed by hydraulic fluid flowing into a closed bottle. The accumulator may also be of another commonly known art, for example a hydraulic ram acting against a spring. As the pressure of the accumulator is charge dependent, the accumulator pressure is utilized for indicating the actual charge of the accumulator.

By regulating the displacement of the second hydraulic machine it is possible to charge the accumulator at a higher pressure than the pressure driving the first hydraulic machine during lowering of the load.

The drives of the first and second hydraulic machines may be connected to an electric motor. Although the motor is termed "electric motor" mainly in order to differentiate this motor from machines acting as hydraulic motors, the motor may take the form of a prime mover such as one or more of an electric motor, a combustion engine or a hydraulic motor that is driven by a separate hydraulic circuit.

The electric machine that is connected to the two hydraulic machines serves several purposes. The connection between the two shafts of two hydraulic displacement machines is in the art called hydraulic transformer. Hydraulic transformer control is known to exhibit difficulties, especially due to non-linearities in a control loop and the machines comparably low inertia compared to the systems pressure level. Here the electric machine adds inertia which easens the control problem. However, the electric machine is even used in order to supply additional power that is dissipated in the hydro-mechanical conversion process, see fig. 2.

The apparatus may include a first valve that is in hydraulic communication with the second fluid machine, the actuator and the accumulator. The first valve is operable between a first position where the second fluid machine is connected to the accumulator, and a second position where the second fluid machine is connected to the actuator.

By operating the first valve to the second position the apparatus may be operated in a conventional manner without recuperation.

The apparatus may further include a second valve that is in hydraulic communication with the accumulator and the actuator, and where the second valve is operable between an open and a closed position.

By opening the second valve, pressurized hydraulic fluid from the accumulator may flow directly between the accumulator and the actuator, for example for boost usage during conventional operation.

In an alternative embodiment the apparatus may include a third valve that is hydraulically positioned between at least the first hydraulic machine or the second hydraulic machine and the reservoir. Normally there is one third valve for each hydraulic machine. The function of the third valve is to direct the flow from the hydraulic machines to the accumulator.

This function is particularly usefull for accumulator charging from lowering loads such as after system operation with boost accumulator usage.The apparatus may include a controller that receives information of at least the relative position of the load and the hydraulic pressure in the accumulator, and based on this information and input from a conventional control system, controls the displacement of the first and second hydraulic machines as well as the power of the electric motor. The controller may be part of the control system that may receive information of the desired load position from say, an operator or a heave compensation system.

The apparatus may be operated by use of a method for recuperation of hydraulic energy from an actuator during part load conditions where more than one hydraulic pump is designed to supply hydraulic fluid to the actuator, wherein the method includes:
- joining at least two pumps mechanically for torque transmission them between, whereby one pump becomes a first hydraulic machine and an other pump becomes a second hydraulic machine;
- arrange a first valve in an actuator pipe between the actuator and the second hydraulic machine;
- activate the first valve to divert hydraulic fluid from the second hydraulic machine away from the actuator when the actuator is supplying hydraulic fluid to the first hydraulic machine.

The method for recuperation of hydraulic energy is suitable for use on a hydraulic apparatus that may include a first drive of a first hydraulic machine and a second drive of a second hydraulic machine are mechanically connected and connected to an electric motor, and where the first hydraulic machine is in hydraulic communication with an actuator, wherein the method may include:
- connecting the second hydraulic machine hydraulically to an accumulator;

- connecting a controller that is designed to control the displacement of the first hydraulic machine, the second hydraulic machine and the motor power to said machines and motor;
- supplying values of load position, actuator pressure and accumulator pressure to the controller; and
- calculating the displacement of the first hydraulic machine, the second hydraulic machine and the motor power based on the values of the load position, actuator pressure and accumulator pressure to the controller.

A controller for this purpose may be designed with the help of one of several methods known to those skilled in the art of control engineering. A principal open loop controller can be stated as follows:

$$\varepsilon_{main} = \frac{i_p \cdot A_p \cdot v_{req}}{D_{m,main} \cdot i_{m,main} \cdot n_{el}} \quad (1)$$

$$\varepsilon_{rec} = \frac{i_p \cdot A_p \cdot v_{req}}{D_{m,rec} \cdot i_{m,rec} \cdot n_{el}} \cdot \frac{P_{Load}}{P_{Acc}} \quad (2)$$

where the $D_{m;main}$ and $D_{m;rec}$ denote the maximum displacement of main machine and the machine intended for energy recuperation respectively, ε denotes the displacement ratio of the two machines and $i_{m;main}$ and $i_{m;rec}$ the number of machines for the two separate purposes. The parameter i_p denotes the number of hydraulic cylinders and A_p their area, the variables P_{Load} and P_{Acc} denote the load and accumulator pressures respectively. The variable v_{req} denotes the require piston speed, and n_{el} the shaft speed of the electric machine.

The method may further include:
- define or identify type of cycle;
- enter a control loop:
    - estimate recuperation potential;

- reconfigure the first and second hydraulic machines and electric motor power;
- monitor and control accumulator charge;
- finish cycle.

The step of a flow chart carried out by the controller during operation may thus include a first step where the type of cycle is defined or identified, a second step where the recuperation potential is estimated. In a third step the hydraulic machines as well as the electric motor are reconfigured accordingly to findings in the second step. A fourth step includes monitoring and control of the charge of the accumulator. The state of the accumulator charge as defined in the fourth step may require a new estimation of the recuperation potential in the second step. The cycle is finished in a fifth step that is entered when the load has reached a desired position.

Change in operational details may be applicable depending on local conditions. The operation will include estimation of available energy for recuperation and control of the second hydraulic machine to recover a major part of available energy to the accumulator, as well as estimation of available energy in the accumulator for use and control of the second hydraulic machine to utilize the major part.

None of the prior art documents discloses an energy management system for cyclic load profiles in order to estimate the energy recuperation potential to a hoisting system where energy is stored in an accumulator.

The apparatus according to the invention is well suited for emergency operation if the electric motor should fail or for providing hydraulic power to other systems.

It is a major benefit of the proposed apparatus that only minor redesign from today's design is necessary, and that no major additional components are required.

It is assumed that the apparatus and method according to the invention best relates to operating conditions significantly below the maximum specification. During these conditions, the existing components can be utilized in a different way, so that energy recuperation can be made possible. In that manner, the recuperated energy from a lowering load can be utilized for a subsequent lifting, so that the installed power of the entire system can be reduced.

Below, an example of a preferred apparatus and method is explained under reference to the enclosed drawings, where:

Fig. 1 shows a principle sketch of a vessel having a crane that is operated by a hydraulic apparatus according to prior art;

Fig. 2 shows the same as in fig. 1, but with a hydraulic apparatus according to the present invention;

Fig. 3 shows a diagram of the principal hydraulic and control circuits of the apparatus;

Fig. 4 shows the diagram in fig. 3, but in an alternative embodiment with additional valves.

Fig. 5 illustrates the use of recuperated hydraulic energy from the accumulator for lifting a load;

Fig. 6 illustrates the recuperation of potential energy into hydraulic energy for storage in an accumulator; and

Fig. 7 shows a flow chart of the steps included in the method according to the invention.

On the drawings the reference number 1 denotes a vessel that includes a crane 2. A load 4 is suspended from the crane 2 and lifted by an actuator 6.

According to prior art as shown in fig. 1, the actuator 6 is connected to a hydraulic apparatus 8 by a pipe 10. The apparatus 8 includes at least two variable hydraulic pumps 12 that are driven by their own electric motor 14.

When lifting the load 4, all energy is delivered by one or more of the electric motors 14. When lowering the load 2, the potential energy is dissipated as heat.

In fig. 2 the vessel 1 is equipped with a hydraulic apparatus 16 for recuperation of potential energy from the load 4.

The hydraulic apparatus 16, that is shown in more detailed in fig. 3, includes a first hydraulic machine 18 and a second hydraulic machine 20, both designed to operate as variable pumps/motors.

The first hydraulic machine 18 has a first drive 22 in the form of a shaft that is connected to an electric motor 24. The electric motor 24 is connected to the second hydraulic machine 20 via a second drive 26 also in the form of a shaft. The first and second drives 22, 26 are thus mechanically connected through the electric motor 24.

Both hydraulic machines 18, 20 communicate with a reservoir 28 for hydraulic fluid.

The first hydraulic machine 18 is connected to the plus-side of an actuator 6 via an actuator pipe 30. The actuator 6, in the form of a hydraulic ram, carries a load 4. When the first hydraulic machine 18 supplies hydraulic fluid via the actuator pipe 30 to the actuator 6, the load 4 is lifted.

The second hydraulic machine 20 is connected to an accumulator 34 via an accumulator pipe 36. A first valve 38 is coupled to the accumulator pipe 36 and to the actuator pipe 30. When activated, the first valve 38 divert the hydraulic connection of the second hydraulic machine 20 from the accumulator 34 and to the actuator 6 as it may be necessary to supply the actuator 6 with hydraulic fluid from both hydraulic machines 18, 20 when the accumulator is working close to its design load and speed.

A second valve 40, see fig. 3, is connected between the actuator pipe 30 and the accumulator pipe 36. When activated, the second valve 40 allows flow of hydraulic fluid between the accumulator 34 and the actuator 6.

A controller 42 receives, via sensor cables 44, information of the relative load position from a position sensor 46, accumulator pressure from a first pressure sensor 48 and accumulator pressure from a second pressure sensor 50.

The controller 42 is designed to control the first and second hydraulic machines 18, 20 and the electric motor 24 via control cables 52.

Fig. 7 shows a flow chart indicting steps carried out by the controller 42 during operation. In step 60 the type of cycle is defined or identified. In step 62 the recuperation potential is estimated. The hydraulic machines 18, 20 as well as the electric motor 24 are reconfigured accordingly in step 64. A step 66 includes monitoring and control of the charge of the accumulator 34. The charge of the accumulator 34 as defined in step 66 may require a new estimation of the recuperation potential in step 62. The cycle is finished in step 68 when the load 4 has reached a desired position.

The steps 60 to 68 as shown in fig. 7 may be implemented using software code stored in a media readable by a computer system not shown but included in the controller 42.

Somewhat simplified, the type of cycles experienced in step 60 include lifting, lowering and keeping the load stationary. The actual type of cycle may be identified by an input signal to the controller 42, or by an actual movement of the load 4.

When the actual cycle, as defined or identified in step 60, is set to be lifting of the load 4, the displacement of the first hydraulic machine 18 is governed by the required lifting speed. An arrow in fig. 5 indicated the energy flow.

In step 62 the possible contribution from energy stored in the accumulator 34 is estimated based on information of the accumulators 34 charge. By utilizing this information and the required power in the first hydraulic machine 18, the displacement of the second hydraulic machine 20, acting as a hydraulic motor, is adjusted in step 64. If required, the electrical motor 24 is controlled in step 64 to supply necessary power.

In step 66 the information of the accumulator 34 charge is monitored. Information is returned to step 62. The feed back from step 66 to step 62 implies that a control loop including the steps 62, 64 and 66 will run until step 68 is entered.

The cycle finishes in step 68 when the load 4 has reached an intended position.

When the actual cycle, as defined or identified in step 60, is set to be lowering of the load 4, the displacement of the first hydraulic machine 18, acting as an hydraulic motor, is governed by the required lowering speed. An arrow in fig. 6 indicates the energy flow.

In step 62, the recuperation potential is estimated based on the available power from the first hydraulic machine 18 as well as on the available energy storage capacity of the accumulator 34. In step 64 the displacement of the second hydraulic machine 20, acting as a hydraulic pump, is set. In the unlikely event that insufficient storage capacity is available in the accumulator 34, surplus energy may be dissipated as heat in an emergency valve that is not shown.

As previously stated, the information of the accumulator 34 charge is monitored in step 66. Information is returned to step 62. The cycle finishes in step 68 when the load 4 has reached an intended position.

If the cycle as defined or identified in step 60 is set to hold the load 4 stationary, the displacement of first hydraulic machine 18 is regulated to compensate for any leaks, while power for this operation is supplied from the accumulator 34 via the second hydraulic machine 20 and/or the electric motor 24.

In an alternative embodiment, see fig. 4, third valves 54 are positioned between the first hydraulic machine 18, the second hydraulic machine 20 and the reservoir. A return pipe 56 connects the third valves 54 with the accumulator.

When not activated, the return pipe 56 is closed at the third valves 54, while the return flow from the hydraulic machines 18, 20 to the reservoir 28 is open. When activated, the third valves 54 divert the return flow from the hydraulic machines 18, 20 through the return pipe 56 to the accumulator 34.

As stated in the general part of the description, this function is particularly useful for charging of the accumulator 34 from lowering loads such as after boost accumulator usage.

C l a i m s

1. An apparatus (16) for recuperation of hydraulic energy from an actuator (6) where a first drive (22) of a first hydraulic machine (18) and a second drive (26) of a second hydraulic machine (20) are mechanically connected, and where the first hydraulic machine (18) is in hydraulic communication with an actuator (6) and where the second hydraulic machine (20) is in hydraulic communication with an accumulator (34), c h a r a c t e r i z e d i n that a first valve (38) is in hydraulic communication with the second hydraulic machine (20), the actuator (6) and the accumulator (34), and where the first valve (38) is operable between a first position where the second hydraulic machine (20) is connected to the accumulator (34) and a second position where the second hydraulic machine (20) is connected to the actuator (6).

2. An apparatus according to claim 1, c h a r a c t e r i z e d i n that the drives (22, 26) are connected to an electric motor (24).

3. An apparatus according to claim 1, c h a r a c t e r i z e d i n that a second valve (40) is in hydraulic communication with the actuator (6) and the accumulator (34) and where the second valve (40) is operable between an open and a closed position.

4. An apparatus according to claim 1, c h a r a c t e r i z e d i n that a third valve (54) that is hydraulically positioned between at least the first hydraulic machine (18) or the second hydraulic machine (20) and the reservoir (28), and where the third valve (54) that communicates with the reservoir (28) is operable between a position where the return flow between the actual hydrau-

lic machine (18, 20) and the reservoir (28) is open and the communication with the accumulator (34) is closed, and a position where flow from the actual hydraulic machine (18, 20) is diverted to the accumulator (34).

5. A apparatus according to claim 2, characterized in that a controller (42) that receives information of at least the relative position of the load (4) and the hydraulic pressure in the accumulator (34), controls the displacement of the first and second hydraulic machines (18, 20) as well as the power of the electric motor (24).

6. A method for recuperation of hydraulic energy from an actuator (6) during part load conditions where more than one hydraulic pump (12) is designed to supply hydraulic fluid to the actuator (6), characterized in that the method includes:
- joining at least two pumps (12) mechanically for torque transmission them between, whereby one pump becomes a first hydraulic machine (18) and another pump (12) becomes a second hydraulic machine (20);
- arrange a first valve (38) in an actuator pipe (30) between the actuator (6) and the second hydraulic machine (20);
- activate the first valve (38) to divert hydraulic fluid from the second hydraulic machine (20) away from the actuator (6) when the actuator (6) is supplying hydraulic fluid to the first hydraulic machine (18)

7. A method according to claim 6 where a first drive (22) of a first hydraulic machine (18) and a second drive (26) of a second hydraulic machine (20) are mechanically connected and connected to an electric motor (24), and where the first hydraulic machine (18) is in hydraulic communi-

cation with an actuator (69), characterized in that the method includes:

- connecting the second hydraulic machine (20) hydraulically to an accumulator (34);
- connecting a controller (42) that is designed to control the displacement of the first hydraulic machine (18), the second hydraulic machine (20) and the power of the electric motor (24) to said machines and motor;
- supplying values of the position of the load (4), the pressure of the actuator (6) and the pressure of the accumulator (34) to the controller (42); and
- calculating the displacement of the first hydraulic machine (18), the second hydraulic machine (20) and the power of the electric motor (24) based on the values of the position of the load (4), the pressure in the actuator (6) and the pressure in the accumulator (34).

8. A method according to claim 6, characterized in that the method further includes:

- identify type of cycle;
- enter a control loop:
    - estimate recuperation potential;
    - reconfigure the first and second hydraulic machines and electric motor power;
    - monitor and control accumulator charge;
- finish the cycle.

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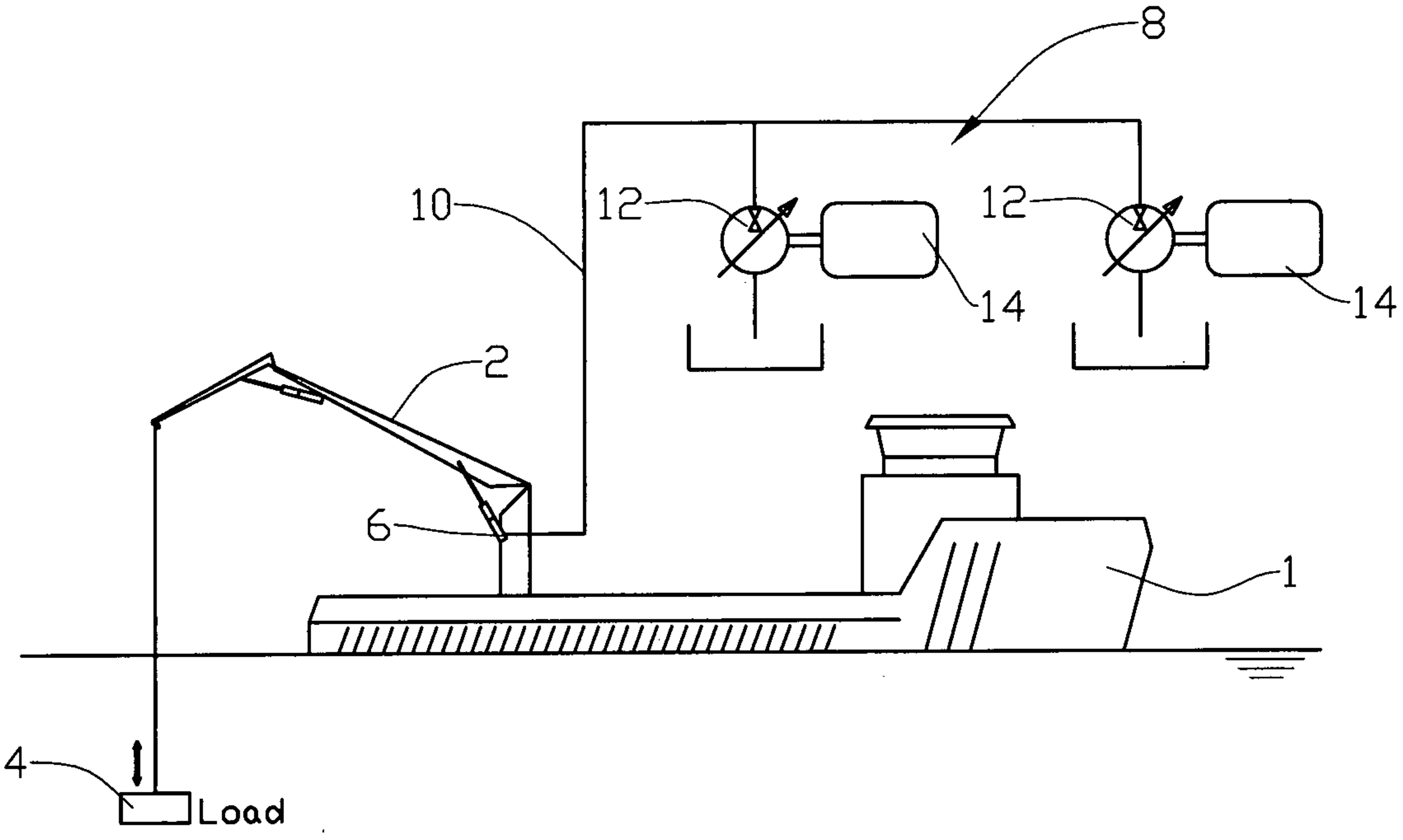

Fig. 1

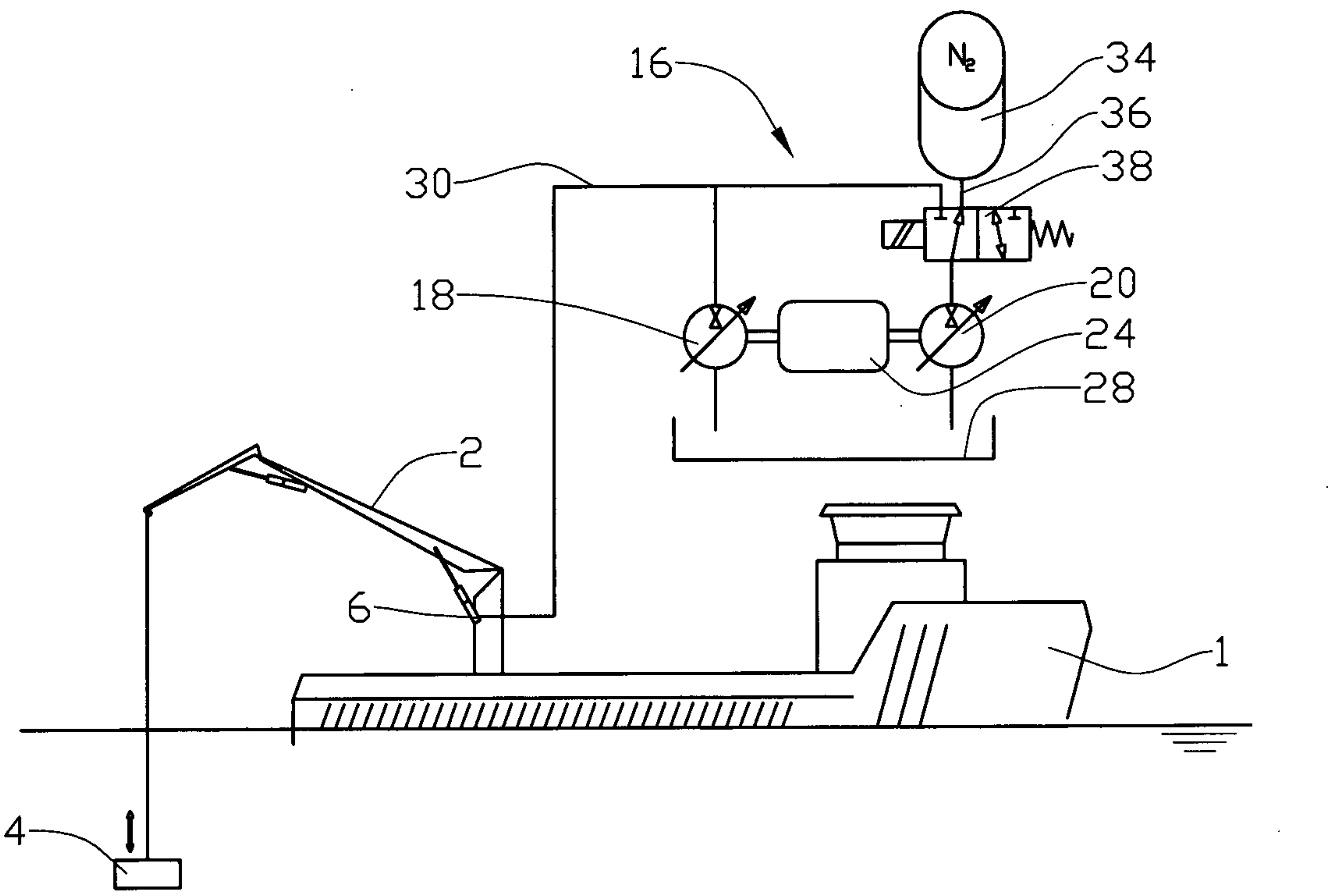

Fig. 2

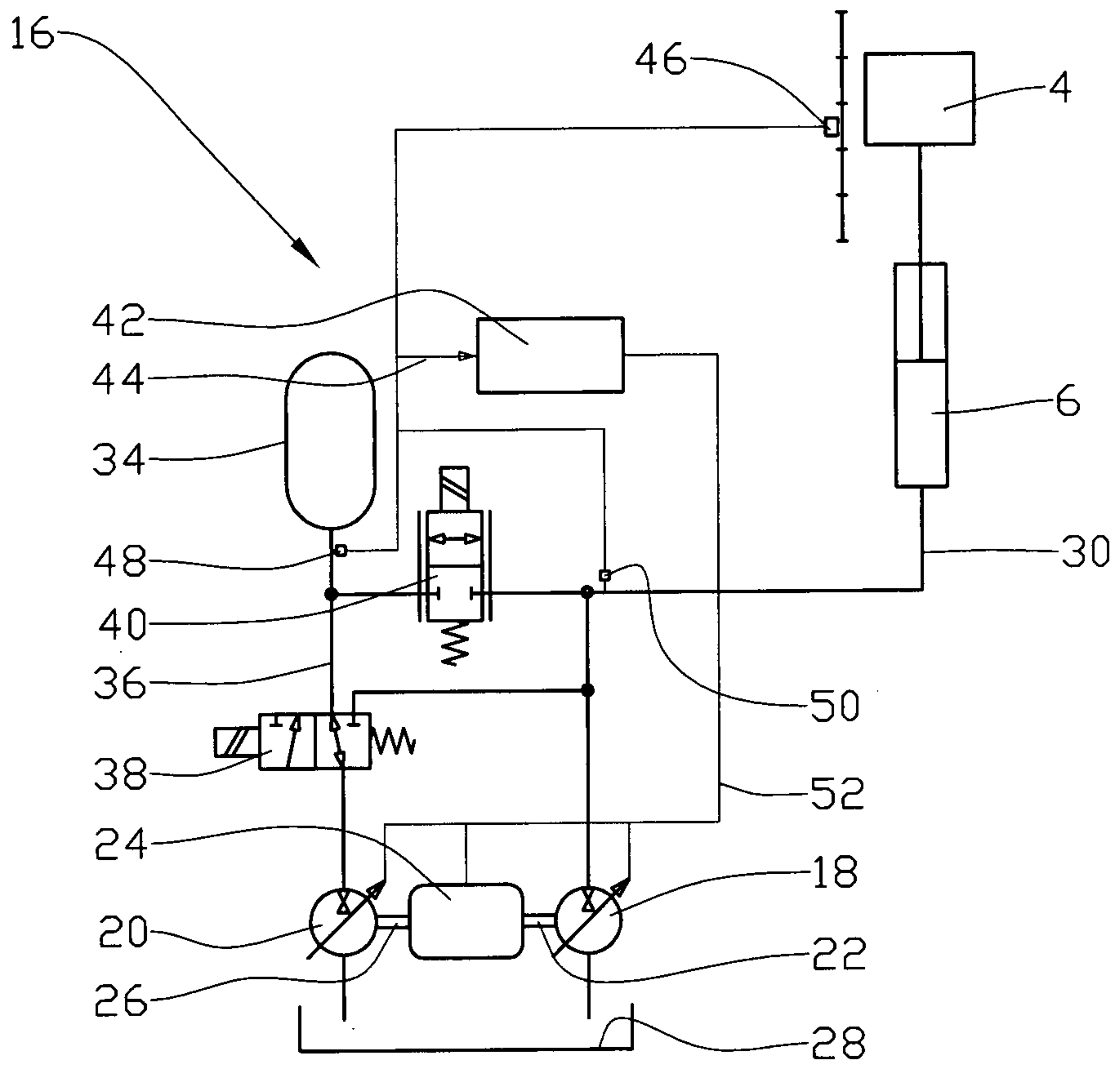

Fig. 3

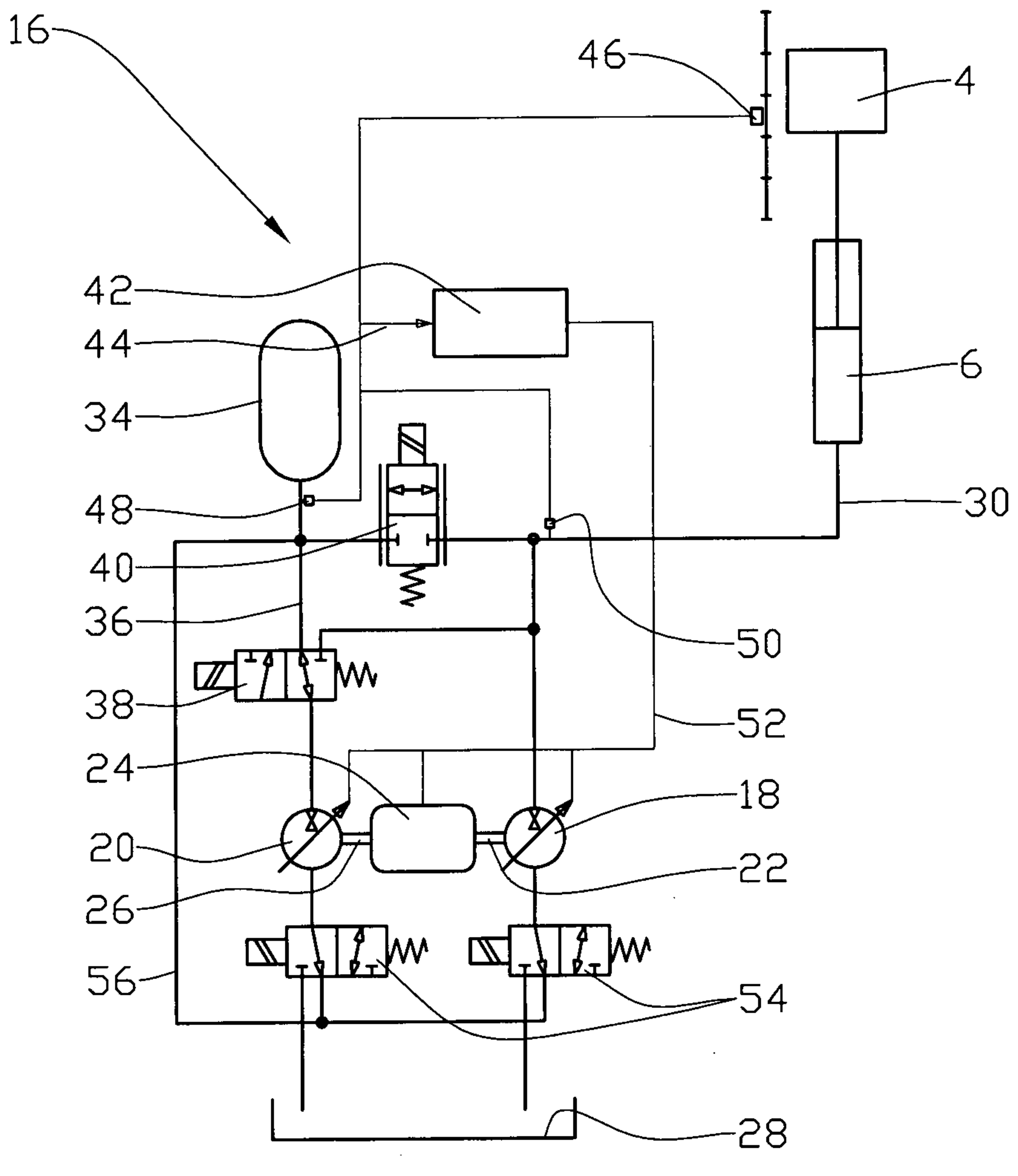

Fig. 4

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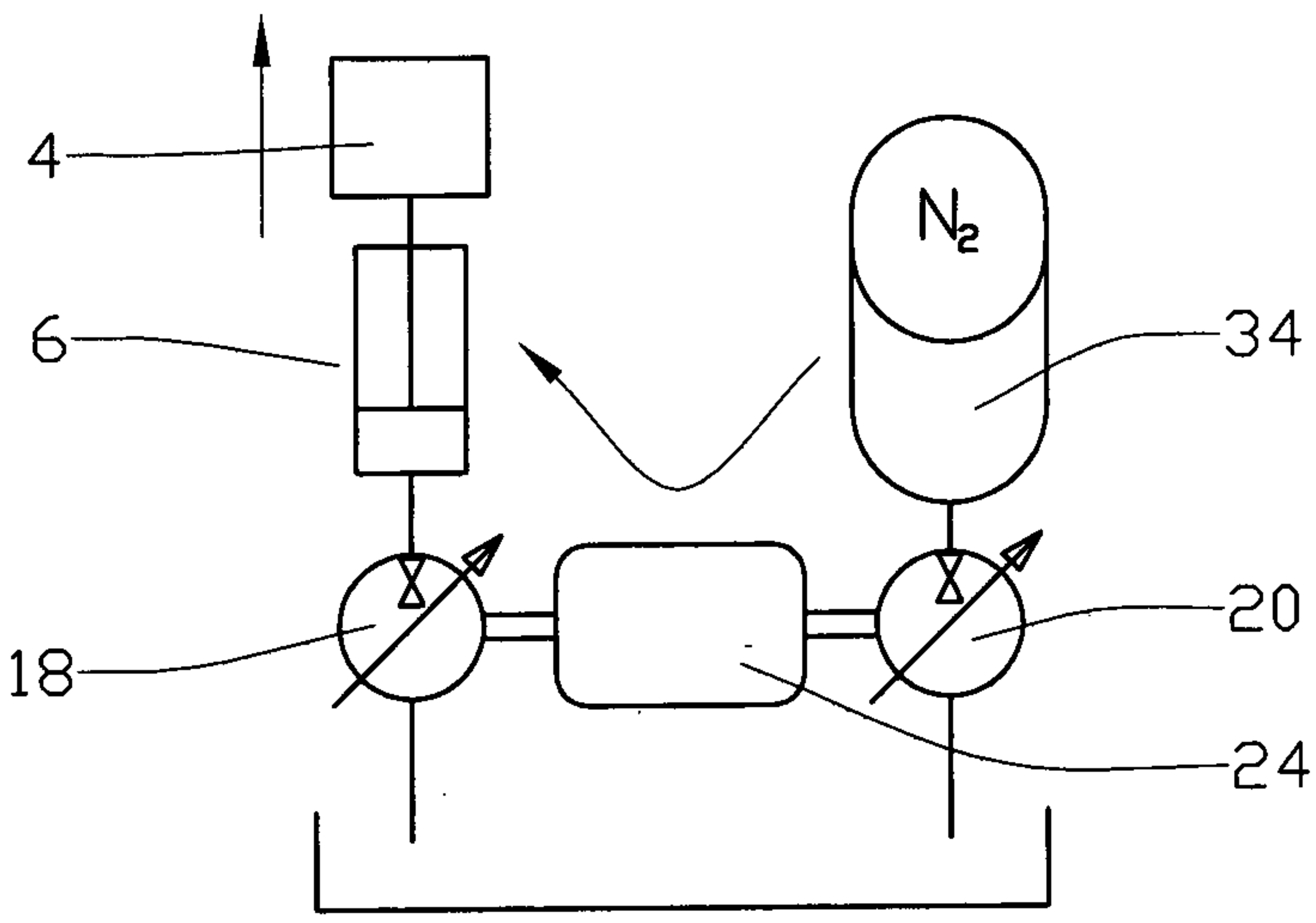

Fig. 5

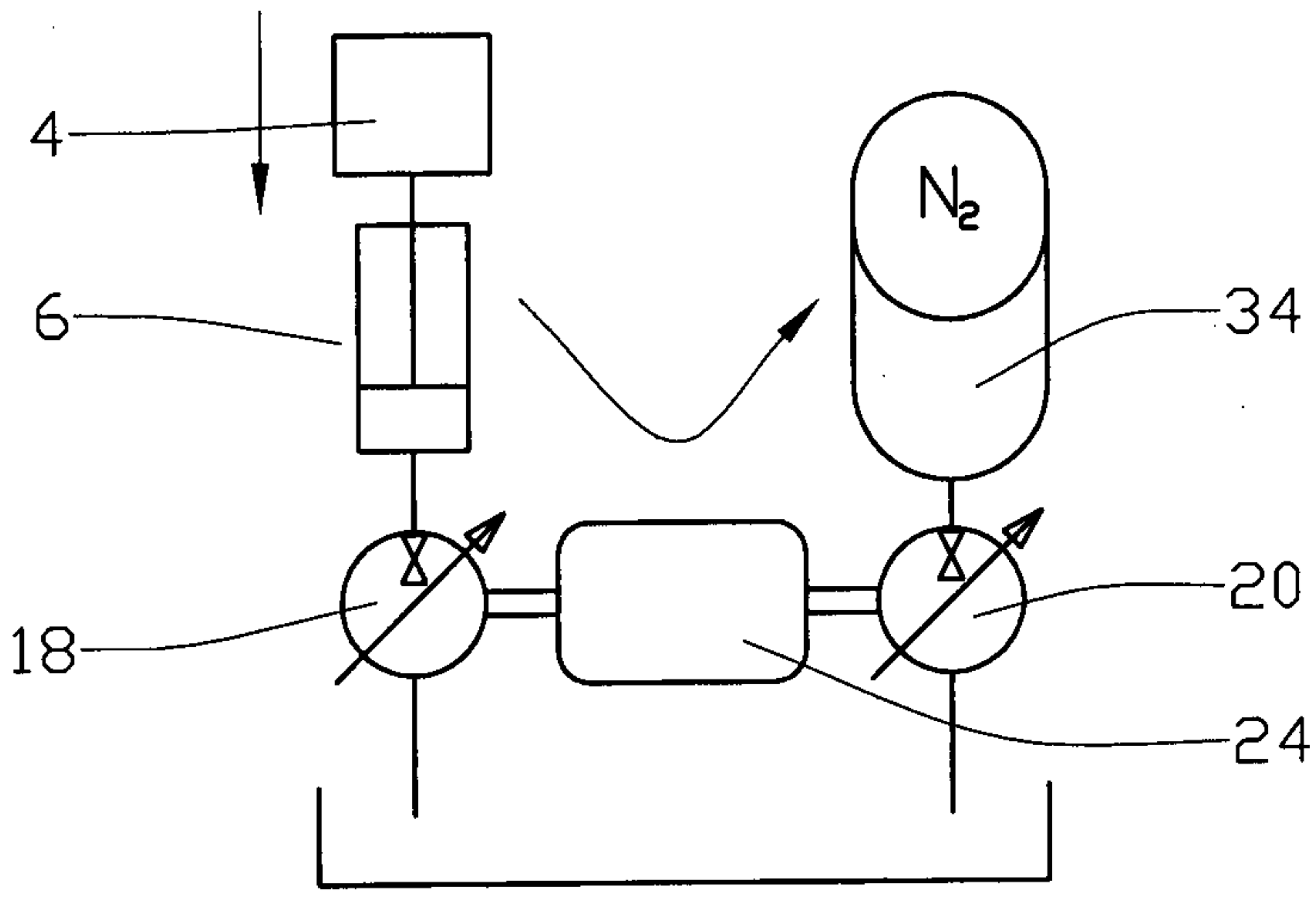

Fig. 6

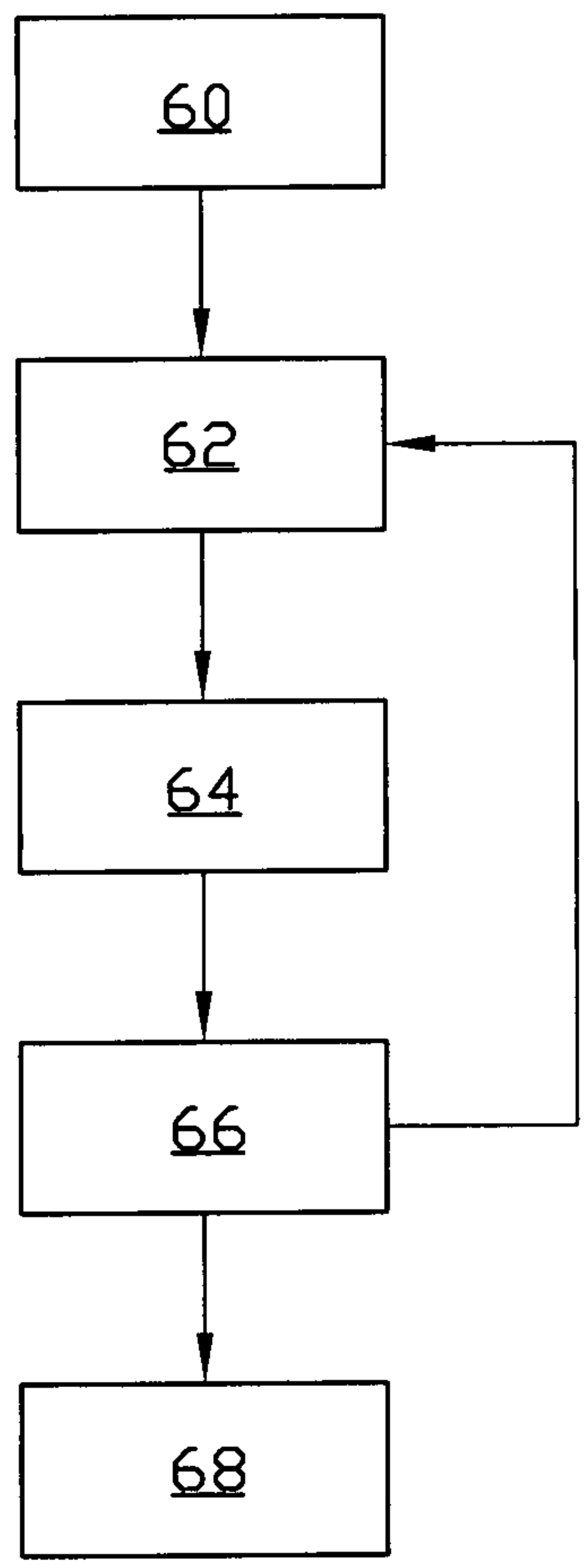

Fig. 7

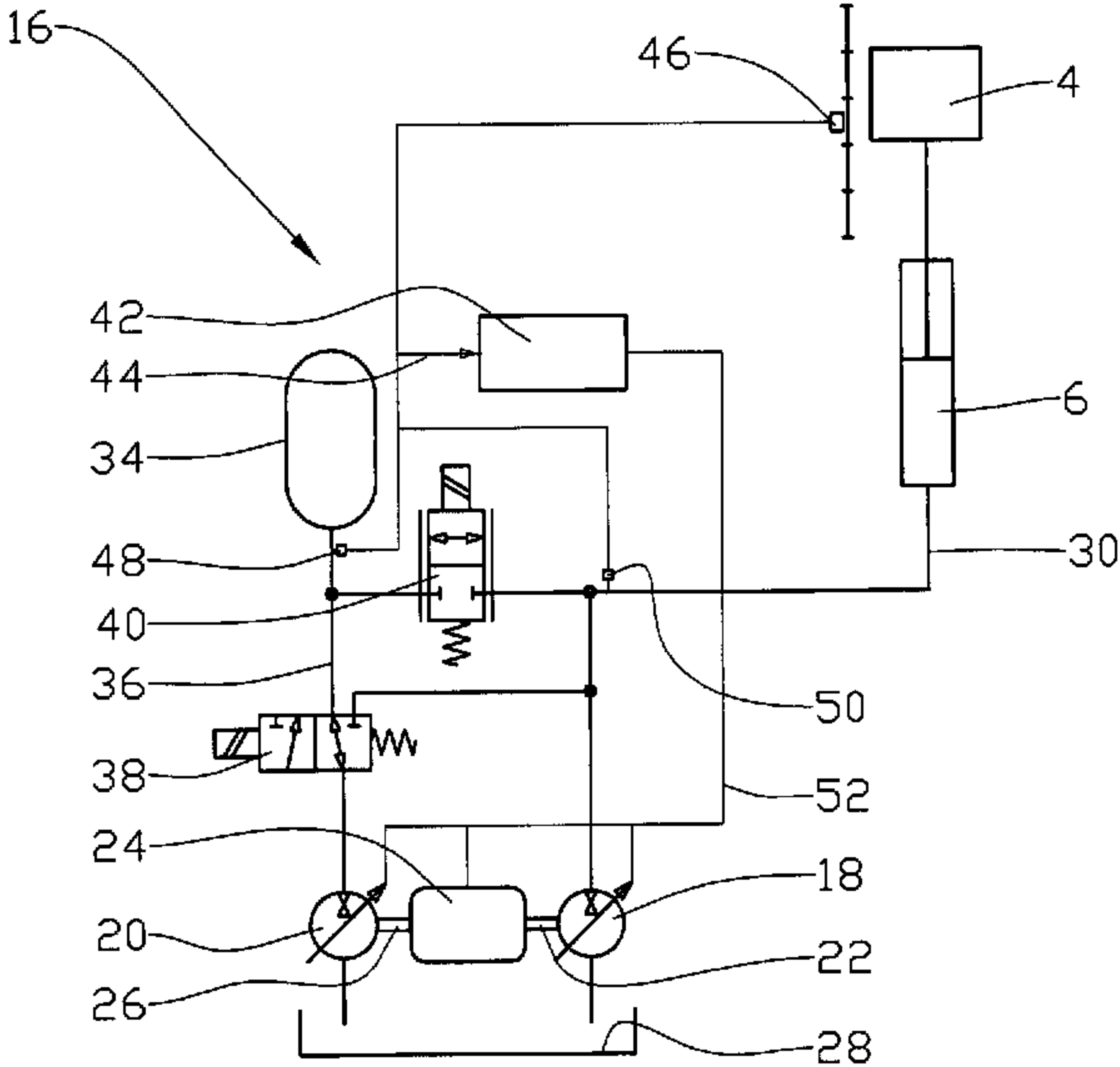

Fig. 3