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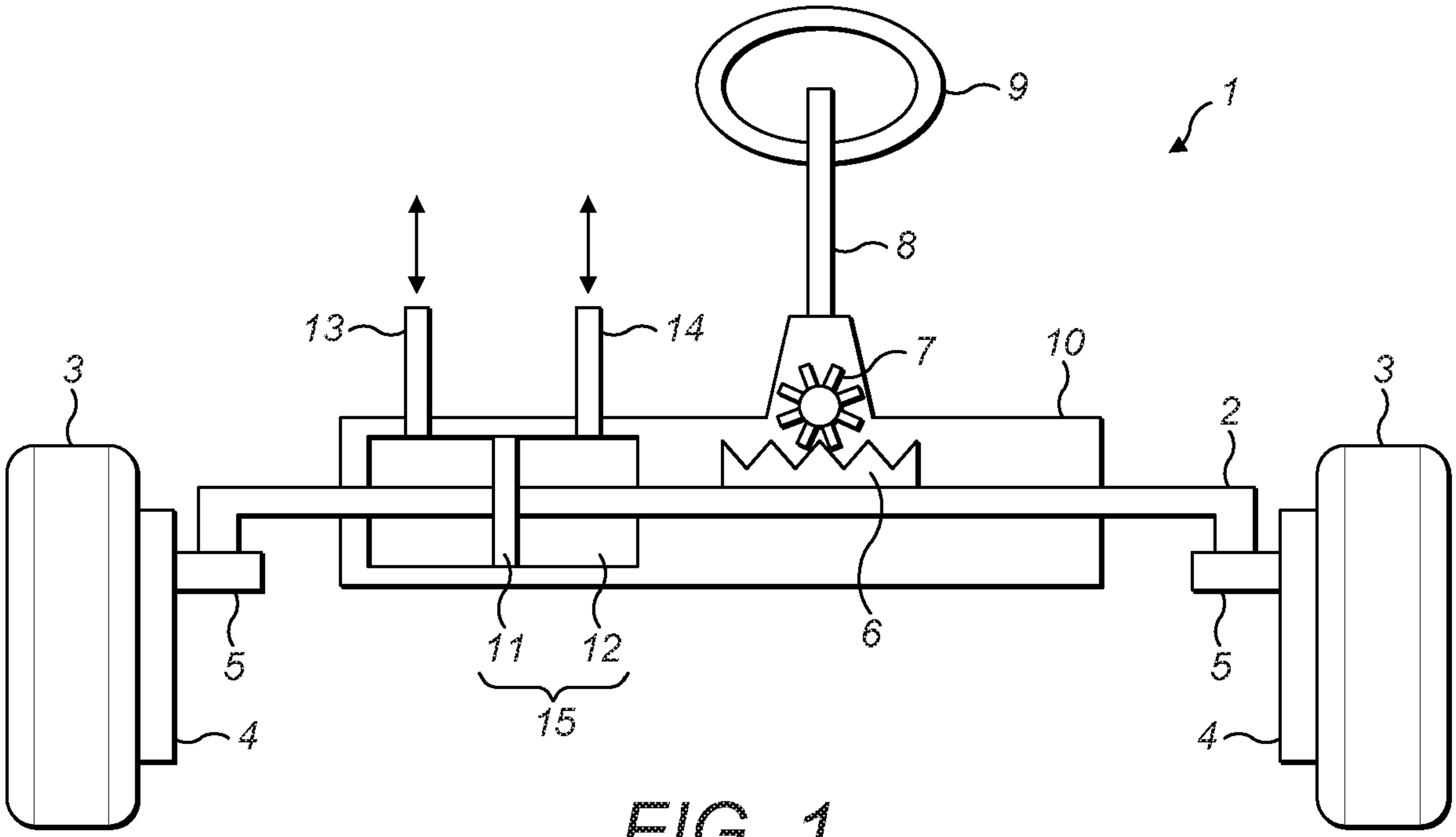
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FIG. 1

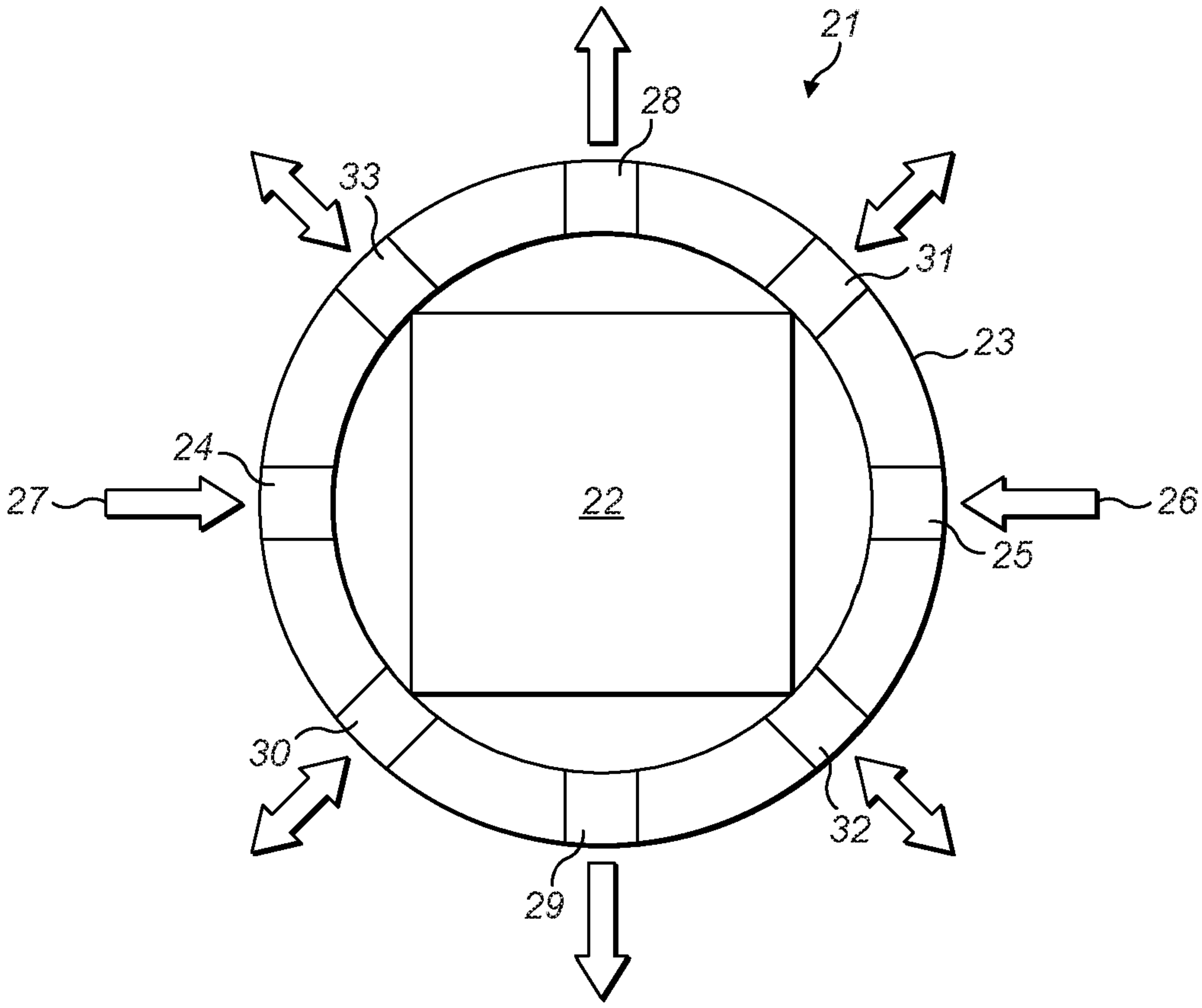
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FIG. 2a

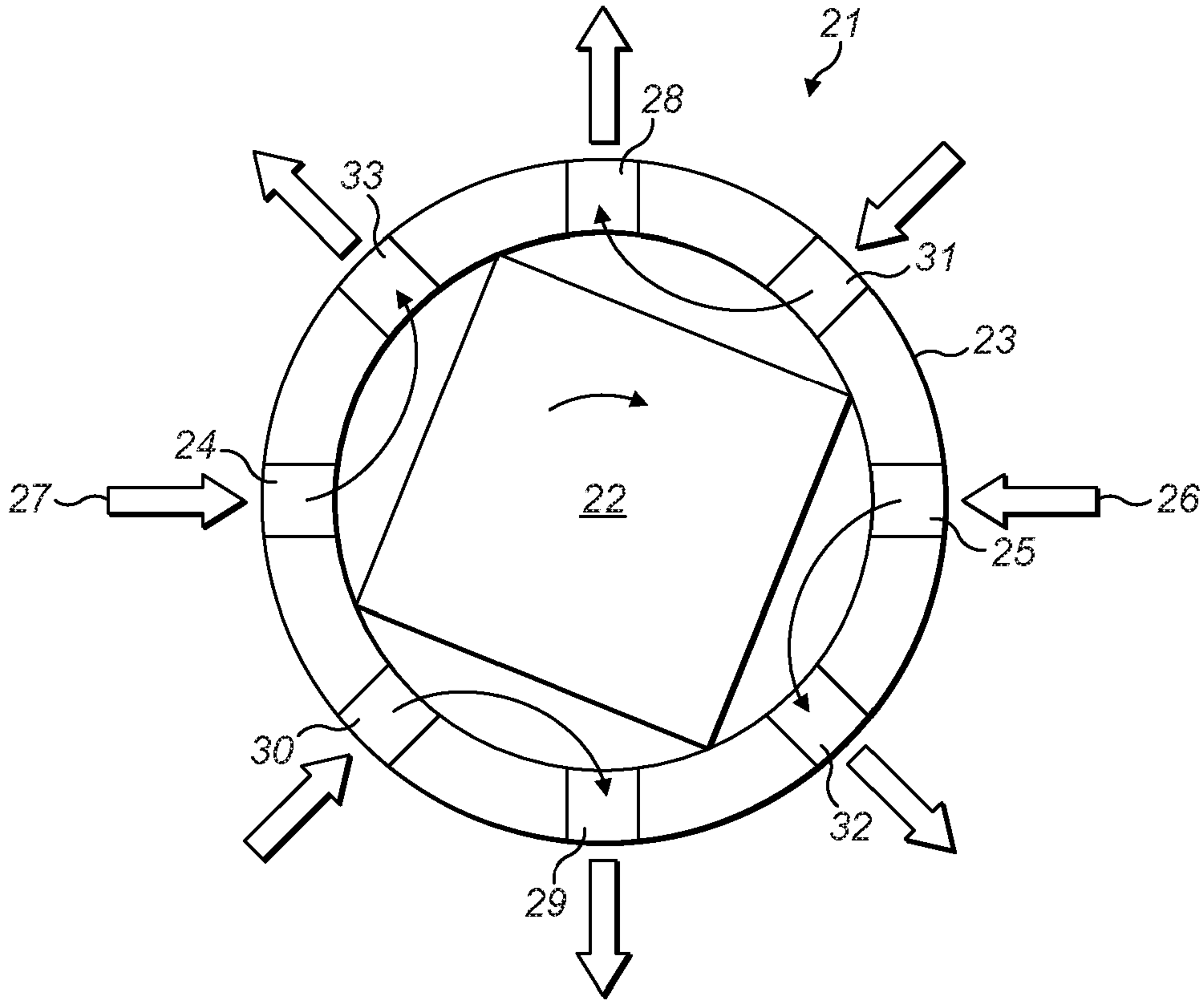
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FIG. 2b

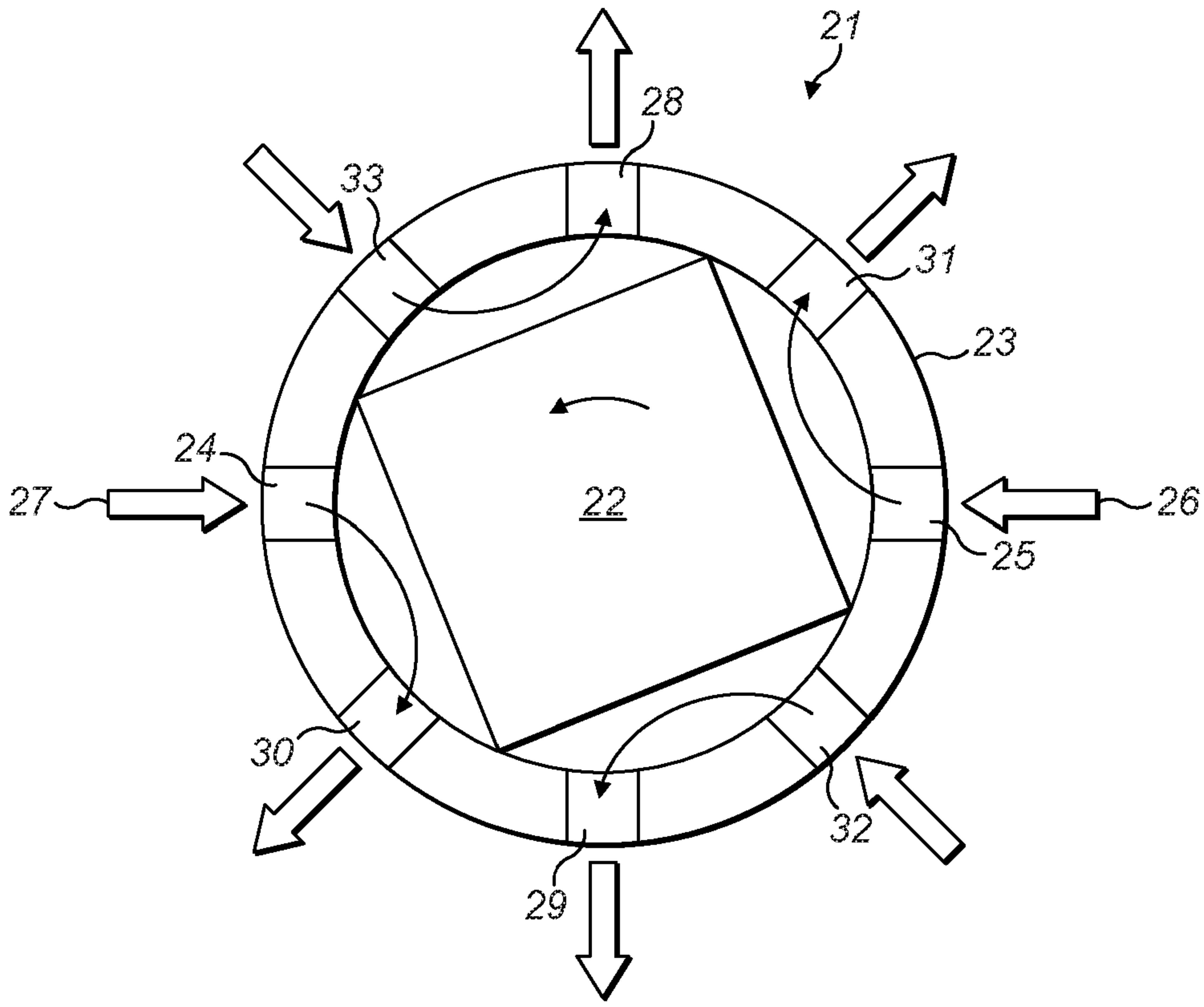
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FIG. 2c

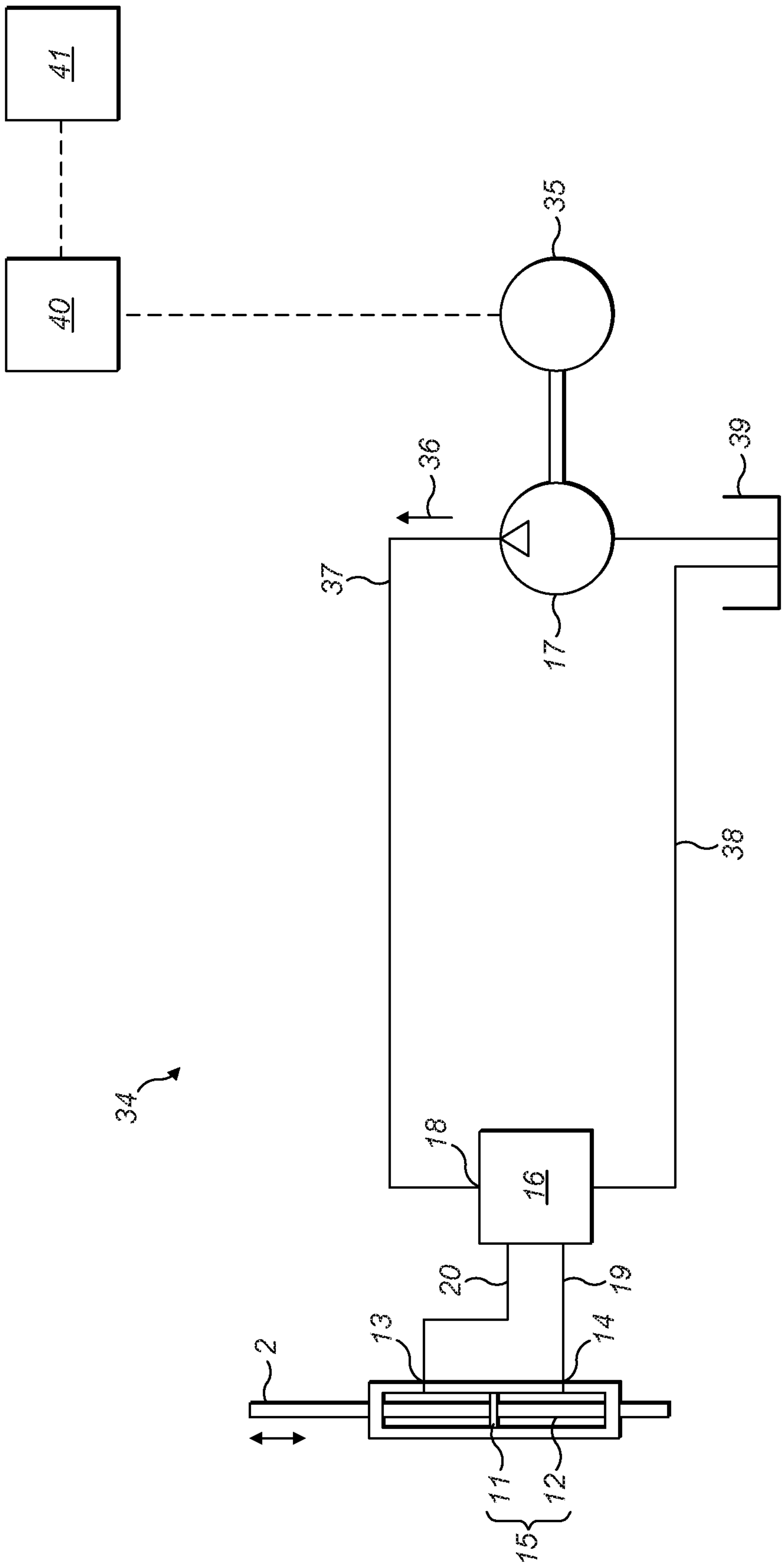

FIG. 3

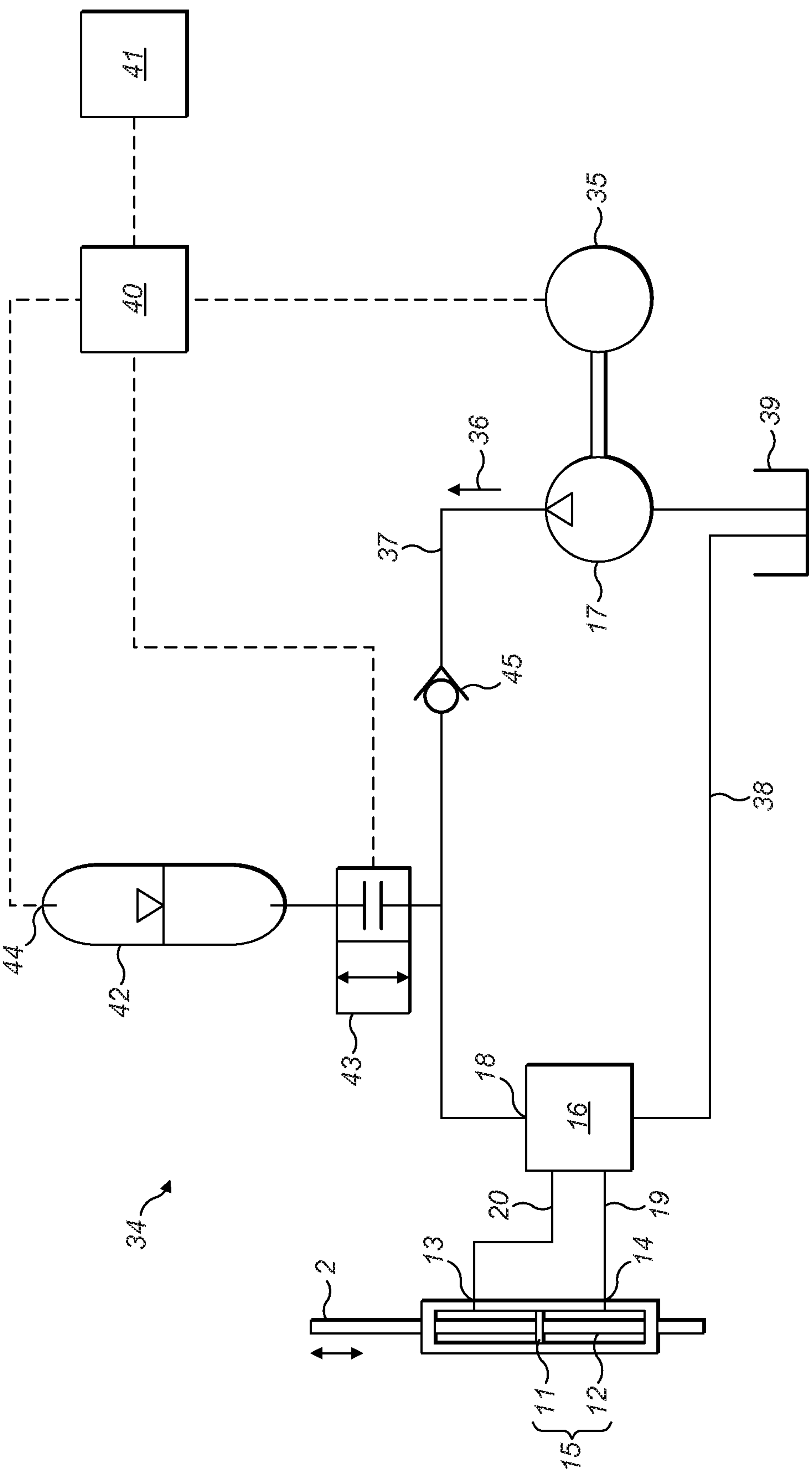

FIG. 4

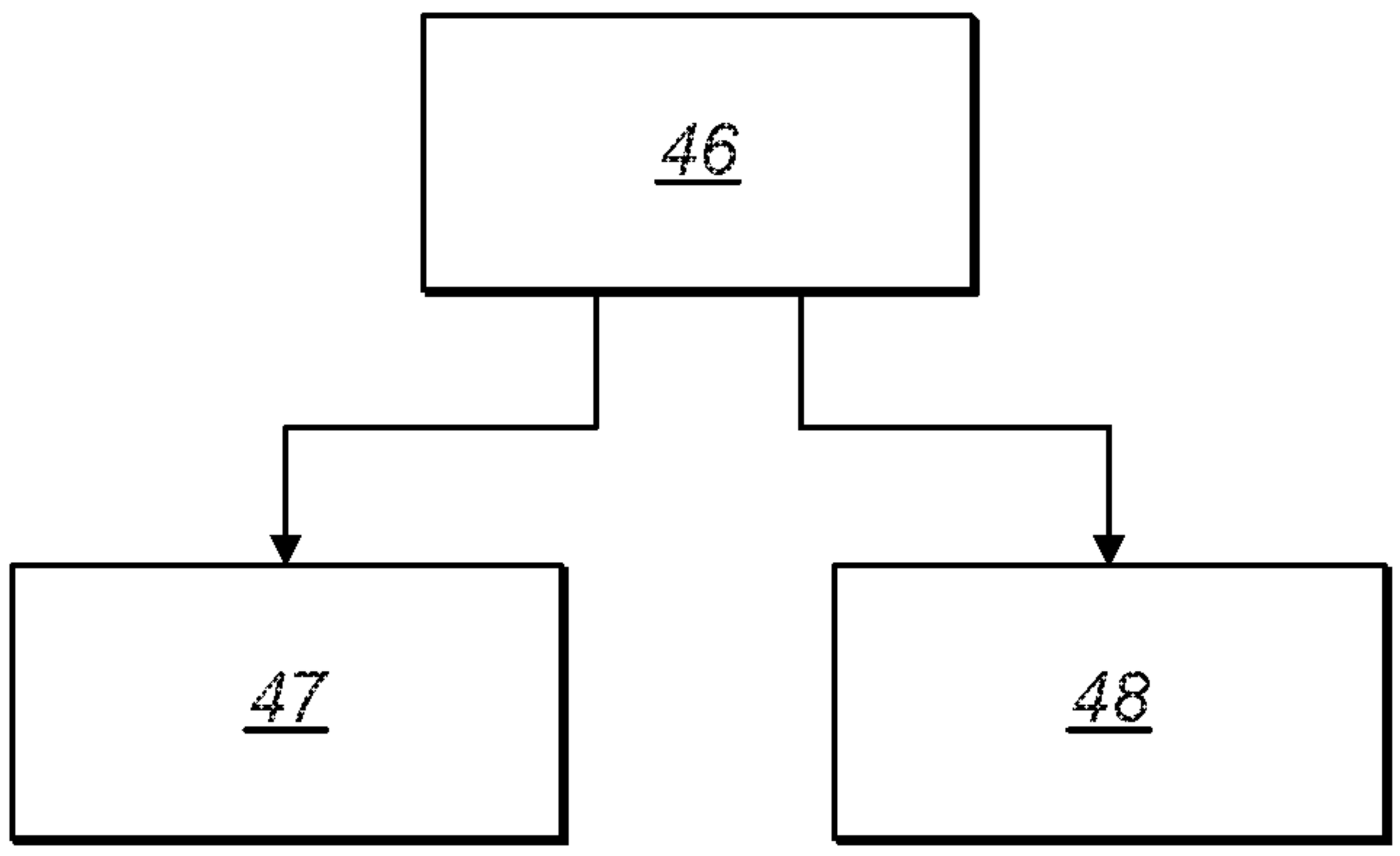

FIG. 5

Electro-Hydraulic Power Steering System

Field of the Invention

The present invention relates to an electro-hydraulic power steering system for an electric vehicle, a controller for an electro-hydraulic power steering system, and a method of controlling an electro-hydraulic power steering system.

Background

It is known to use an electric pump to provide hydraulic pressure to a hydraulic power steering system. Such a system is termed an electro-hydraulic power steering system. The electric pump generates hydraulic pressure which is provided to a hydraulic actuator that acts on the steering rack (and wheels) in response to movement of the steering wheel.

Summary of the Invention

In accordance with some embodiments, there is provided an electro-hydraulic power steering system for an electric vehicle, the system comprising:

a hydraulic actuator arranged to act on a steering rack of said electric vehicle;

a pump adapted to provide hydraulic pressure to the hydraulic actuator via a pipe;

an accumulator connected to the pipe and arranged to hold hydraulic fluid under pressure; and,

a valve arranged between the accumulator and the pipe such that, during use, when the valve is closed the accumulator is isolated from the pipe and hydraulic fluid from the pump is provided to the hydraulic actuator via the pipe, and when the valve is open hydraulic fluid held in the accumulator is provided to the hydraulic actuator via the pipe.

The electro-hydraulic power steering system may further comprise a controller configured to control the valve.

The controller may be further configured to control operation of the pump.

The controller may be further configured to determine a power steering requirement of said electric vehicle.

The electro-hydraulic power steering system may further comprise a device adapted to determine an operating characteristic of said vehicle, and wherein the controller is configured to determine the power steering requirement of said electric vehicle according to said operating characteristic.

The device may be configured to determine a current power steering requirement of said electric vehicle.

Alternatively or additionally, the device may be adapted to predict an upcoming power steering requirement of said electric vehicle.

In one example, the device may comprise a sensor adapted to measure a parameter associated with a steering wheel of said electric vehicle.

In particular, the device may comprise a steering wheel angle sensor, or may alternatively comprise a steering wheel torque sensor.

In other examples, the device comprises a vehicle speed sensor.

In another example, the device comprises a vehicle-location device for determining a location of said electric vehicle.

In yet another example, the device comprises a vehicle-navigation device for displaying and/or planning a route for said electric vehicle.

The controller may be configured to control operation of the pump according to the power steering requirement. In particular, the controller may be configured to control operation of the pump according to the current power steering requirement and/or the predicted upcoming power steering requirement.

The controller may be configured to reduce the operating speed of the pump in response to a reduction in the power steering requirement, and to increase the operating speed of the pump in response to an increase in the power steering requirement.

The controller may be configured to open the valve in response to an increase in the power steering requirement.

The electro-hydraulic power steering system may further comprise a pressure sensor arranged to measure a pressure within the accumulator.

The controller may be configured to open the valve for recharging the accumulator.

The controller may be configured to close the valve when the pressure within the accumulator reaches a predetermined value.

The controller may be configured to operate the pump when the pressure within the accumulator is below a predetermined value.

The electro-hydraulic power steering system may further comprise a check valve disposed in the pipe between the pump and the connection to the accumulator.

The hydraulic actuator may comprise a power steering box, and a hydraulic ram arranged to act on said steering rack.

In accordance with some embodiments, there is also provided an electric vehicle comprising the electro-hydraulic power steering system described above.

In accordance with some embodiments, there is also provided a controller for an electro-hydraulic power steering system for an electric vehicle, the steering system comprising:

a hydraulic actuator arranged to act on a steering rack of said electric vehicle;

a pump adapted to provide hydraulic pressure to the hydraulic actuator via a pipe;

an accumulator connected to the pipe and arranged to hold hydraulic fluid under pressure; and,

a valve arranged between the accumulator and the pipe such that, during use, when the valve is closed the accumulator is isolated from the pipe and hydraulic fluid from the pump is provided to the hydraulic actuator via the pipe, and when the valve is open hydraulic fluid held in the accumulator is provided to the hydraulic actuator via the pipe;

wherein the controller is configured to determine a power steering requirement of said electric vehicle and the controller is configured to open the valve in response to an increase in the power steering requirement.

The controller may be further configured to control operation of the pump according to the power steering requirement.

The controller may be further configured to reduce the operating speed of the pump in response to a reduction in the power steering requirement, and to increase the operating speed of the pump in response to an increase in the power steering requirement.

The controller may be further configured to open the valve if the operating speed of the pump is insufficient for the determined power steering requirement.

In some examples, the device may be configured to determine a current power steering requirement of said electric vehicle.

In other examples, the controller may be configured to predict an upcoming power steering requirement of said electric vehicle.

The electro-hydraulic power steering system may further comprise a pressure sensor arranged to measure a pressure within the accumulator.

In this case, the controller may be configured to open the valve for recharging the accumulator.

Additionally or alternatively, the controller may be configured to close the valve when the pressure within the accumulator reaches a predetermined value.

Additionally or alternatively, the controller may be configured to operate the pump when the pressure within the accumulator is below a predetermined value.

In accordance with some embodiments, there is also provided a method of controlling an electro-hydraulic power steering system for an electric vehicle, the steering system comprising:

a hydraulic actuator arranged to act on a steering rack of said electric vehicle;

a pump adapted to provide hydraulic pressure to the hydraulic actuator via a pipe;

an accumulator connected to the pipe and arranged to hold hydraulic fluid under pressure;

a valve arranged between the accumulator and the pipe such that, during use, when the valve is closed the accumulator is isolated from the pipe and hydraulic fluid from the pump is provided to the hydraulic actuator via the pipe, and when the valve is open hydraulic fluid held in the accumulator is provided to the hydraulic actuator via the pipe; comprising the steps of:

determining a power steering requirement of said electric vehicle; and,

opening the valve in response to an increase in the power steering requirement.

The method may further comprise the steps of reducing the operating speed of the pump in response to a reduction in the power steering requirement, and increasing the operating speed of the pump in response to an increase in the power steering requirement.

The method may further comprise the steps of determining whether the operating speed of the pump is sufficient for the determined power steering requirement; and, opening the valve if the operating speed of the pump is insufficient for the determined power steering requirement.

The step of determining a power steering requirement of said electric vehicle may additionally or alternatively comprise determining a current power steering requirement.

The step of determining a power steering requirement of said electric vehicle may comprise predicting an upcoming power steering requirement.

The method may further comprise the steps of measuring pressure within the accumulator, and closing the valve when the pressure within the accumulator reaches a threshold.

In accordance with some embodiments, there is also provided a method of controlling an electro-hydraulic power steering system for an electric vehicle, the method comprising:

generating hydraulic pressure for said steering system using a pump;

charging an accumulator with hydraulic fluid;

determining a power steering requirement of said electric vehicle;

controlling a the pump according to said determined power steering requirement; and,

releasing hydraulic fluid from the accumulator in response to an increase in said determined power steering requirement.

The method may further comprise the steps of reducing the operating speed of the pump in response to a reduction in the power steering requirement, and increasing the operating speed of the pump in response to an increase in the power steering requirement.

The step of determining a power steering requirement of said electric vehicle may comprise determining a current power steering requirement.

Alternatively or additionally, the step of determining a power steering requirement of said electric vehicle may comprise predicting an upcoming power steering requirement.

In accordance with some embodiments, there is also provided apparatus comprising means for performing the method described above.

In accordance with some embodiments, there is also provided computer-readable instructions which, when executed by computing apparatus, cause the computing apparatus to perform the method described above.

Brief Description of the Drawings

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

FIG. 1 shows a schematic diagram of a steering system for a vehicle, the steering system including a hydraulic ram;

FIGS. 2a, 2b and 2c show schematic diagrams of a valve assembly of a power steering box for connection to the steering system of FIG. 1;

FIG. 3 shows a system diagram for a first example of an electro-hydraulic system for supplying hydraulic pressure to the power steering box of FIG 2;

FIG. 4 shows a system diagram for a second example of an electro-hydraulic system for supplying hydraulic pressure to the power steering box of FIG 2; and,

FIG. 5 shows a flow diagram of a method of controlling the electro-hydraulic power steering system of FIG. 4.

Detailed Description

FIG. 1 shows a steering system 1 for a vehicle, for example an electric vehicle. The steering system 1 includes a steering rack 2 that is connected to the wheels 3 such that movement of the steering rack 2 affects movement of the wheels 3. In the view shown in FIG. 1, the steering rack 2 can move side to side and is attached to wheel carriages 4 via offset pivots 5 such that movement of the steering rack 2 causes the angle of the wheels 3 to change.

The steering rack 2 includes a rack gear 6 that engages with a pinion gear 7 of a steering wheel shaft 8. In this way, the steering wheel 9 is coupled to the steering rack 2 such that rotation of the steering wheel 9 causes the pinion gear 7 to rotate and the rack gear 6, together with the steering rack 2, is moved side to side to actuate the steering action.

As shown in FIG. 1, the steering rack 2 is located within a housing 10.

The steering system 1 of FIG. 1 has a hydraulic power assistance system. In particular, the steering rack 2 includes a piston 11 that is attached to the steering rack 2, and a hydraulic cylinder 12 is formed within the housing 10 such that it surrounds the piston 11. The piston 11 can move within the hydraulic cylinder 12 and seals against the wall of the hydraulic cylinder 12. The hydraulic cylinder 12 is sealed within the housing 10. With the wheels 3 in a central position (i.e. pointing straight), the piston 11 is located approximately centrally of the hydraulic cylinder 12, as shown in FIG. 1. The piston 11 and hydraulic cylinder 12 together form a hydraulic ram 15.

Ports 13, 14 are provided in the wall of the hydraulic cylinder 12 (in the housing 10) on either side of the piston 11. In this way, hydraulic pressure can be provided to one side of the piston 11 to drive the steering rack 2 in one direction, or hydraulic pressure can be provided to an opposite side of the piston 11 to drive the steering rack 2 in an opposite direction. Therefore, the hydraulic ram 15 can be used to urge the steering rack 2 in either direction, providing hydraulic assistance to the steering action.

The ports 13, 14 in the hydraulic cylinder 12 are connected to a power steering box 16, shown in FIG. 3 and schematically illustrated in FIGS. 2a, 2b and 2c. As shown in FIG. 3, the power steering box 16 receives high pressure hydraulic fluid from a pump 17 via an inlet 18, and directs that hydraulic fluid along one of two outlets 19, 20, depending on the position of the steering wheel. Also illustrated in FIG. 3, the outlets 19, 20 of the power steering box 16 are connected to the ports 13, 14 of the hydraulic ram 15.

In particular, the first outlet 19 of the power steering box 16 is connected to port 14 of the hydraulic ram 15, and a second outlet 20 is connected to the other port 13 of the hydraulic ram 15.

In this way, the position of the steering wheel 9 determines the side of the hydraulic cylinder 12 to which hydraulic fluid is provided, and therefore the direction in which the hydraulic force acts on the piston 11 and steering rack 2.

FIGS. 2a, 2b and 2c schematically illustrate a valve system 21 of the power steering box 16 (see FIG. 3). As shown, the valve system 21 includes a valve member 22 located within a housing 23. The valve member 22 is coupled to the steering wheel 9 such that rotation of the valve member 22 within the housing 23 is caused by rotation of the steering wheel 9. The housing 23 includes multiple ports, as explained below, and rotation of the valve member 22 within the housing 23 causes different ports to be connected and disconnected depending on the rotational movement of the steering wheel 9 and the rotational position of the valve member 22.

The valve member 22 may be coupled to the steering wheel 9 via a torsion bar, which twists according to the torque applied to the steering wheel 9. The torsion bar ensures that hydraulic steering assistance is provided only when the steering wheel 9 is being moved (i.e. has torsion applied to it), and not when the steering wheel 9 is in a stationary position and there is no torque.

FIG. 2a shows the valve system 21 of the power steering box 16 (see FIG. 3) in a central position, when the steering wheel 9 and wheels 3 (see FIG. 1) pointed straight.

Port 24 and port 25, located on opposite sides of the housing 23, are connected to a pump and so receive hydraulic fluid under pressure, as illustrated by arrows 26 and 27. Port 28 and port 29 are connected to a return pipe that returns hydraulic fluid to the pump (17, see FIG. 3), via a reservoir (as explained with reference to FIG. 3). Port 30 and port 31 are both connected to a left hand side of the hydraulic cylinder 12 illustrated in FIG. 1, in particular port 13 (see FIG. 1). That is, the side of the hydraulic cylinder 12 that moves the wheels 3 to the left when hydraulic pressure is provided to that side (see FIG. 1). Port 32 and port 33 are both connected to a right hand side of the hydraulic cylinder 12 illustrated in FIG. 1, in particular port 14 (see FIG. 1). That is, the side of the hydraulic cylinder 12 that moves the wheels 3 to the right when hydraulic pressure is provided to that side.

In the central position illustrated in FIG. 2a, hydraulic pressure from the pump, when the pump is on, acts equally on both sides of the valve member 22 and so the valve member 22 does not move. The hydraulic fluid moves around the valve member 22 and exits the valve system 21 via ports 28 and 29, thereby returning to an inlet of the pump 17 (see FIG. 1). Equal hydraulic pressure is provided to all of ports 30, 31, 32 and 33, so in this position there is no net hydraulic force acting on the piston 11 in the hydraulic ram 15 (see FIG. 1).

FIG. 2b illustrates the position of the valve member 22 during a right hand turn. As shown, the valve member 22 has been rotated to the right, and has altered the connections between the ports. In this position, hydraulic fluid from port 24 and port 25, which both receive hydraulic fluid from the pump (17, see FIG. 3), is directed to port 32 and port 33, respectively, and thus to the right hand side of the hydraulic cylinder 12 (see FIG. 1). This causes movement of the piston 11 within the hydraulic cylinder 12 (see FIG. 1), providing power assistance to the steering action. Fluid displaced from the left hand side of the hydraulic cylinder 12 (see FIG. 1) returns to the valve assembly 21 via port 30 and port 31, and is then directed out of the valve assembly 21 via port 28 and port 29, thereby returning to the pump 17 (see FIG. 3).

FIG. 2c illustrates the position of the valve member 22 during a left hand turn. As shown, the valve member 22 has been rotated to the left, and has altered the connections between the ports. In this position, hydraulic fluid from port 24 and port 25, which both receive hydraulic fluid from the pump (17, see FIG. 3), is directed to port 30 and port 31 respectively, and thus to the left hand side of the hydraulic cylinder 12 (see FIG. 1). This causes movement of the piston 11 within the hydraulic cylinder 12 (see FIG. 1), providing power assistance to the steering action. Fluid displaced from the right hand side of the hydraulic cylinder 12 (see FIG. 1) returns to the valve assembly 21 via port 32 and port 33, and is then directed out of the valve assembly 21 via port 28 and port 29, thereby returning to the pump 17 (see FIG. 3).

In this way, the hydraulic pressure generated by the pump 17 (see FIG. 3) is used to assist the steering action.

The steering system 1 described with reference to FIG. 1 is a rack and pinion system, with a separate hydraulic ram 15 and power steering box 16. However, it will be appreciated that other forms of hydraulic power steering systems could be used.

For example, the steering system may alternatively include a steering gear box, where rotation of the steering wheel 9 causes rotation of a worm gear that affects movement of a piston within a housing. Movement of the piston is then translated to movement of the steering rack. Pressurised hydraulic fluid can be provided to opposing sides of the piston within the housing, depending on the position of the steering wheel, to assist movement of the piston and therefore assist the steering action.

In other examples, the steering action may be powered entirely by hydraulic force provided by a pump and hydraulic steering system, without a mechanical linkage between the steering wheel 9 and the wheels 3. In these examples, there is no rack 6 and pinion 7 connection between the steering wheel shaft 8 and the steering rack 10.

FIG. 3 shows a system diagram for an electro-hydraulic system 34 that provides hydraulic pressure to the power steering box 16 described above. In FIG. 3, hydraulic pipes are shown in solid lines, while electrical connections are shown in dotted lines.

The electro-hydraulic system 34 shown in FIG. 3 includes a pump 17 that is driven by an electric motor 35. The previously described power steering box 16 and hydraulic actuator 15 are also shown in FIG. 3.

The pump 17, when driven by the electric motor 35, generates a flow of hydraulic fluid in the direction of arrow 36. The pump 17 therefore provides pressurised hydraulic fluid directly to the power steering box 16 via pipe 37. In this example, pipe 37 constitutes the high pressure side of the system 34 because the hydraulic fluid is under pressure from the pump 17.

The return pipe 38 from the power steering box 16 returns hydraulic fluid to the pump 17.

Optionally, the electro-hydraulic system 34 may include a hydraulic reservoir 39, located on the return pipe 38, between the power steering box 16 and the inlet of the pump 17. Such a reservoir 39 may be used to ensure adequate supply of hydraulic fluid to the pump 17 at all times.

In this example, pipe 38 and reservoir 39 constitute the low pressure side of the system 34.

As illustrated in FIG. 3, the system includes a controller 40. The controller 40 is arranged to control operation of the electric motor 35, and therefore also the pump 17. The skilled person will appreciate that in some examples, the pump 17 and electric motor 35 may be separate components linked by a shaft, as illustrated in FIG. 3, or the pump 17 and electric motor 35 may alternatively be integrated with each other.

The controller 40 may be configured to operate the pump 17 according to a power steering requirement. This may be a current power steering requirement, or an upcoming power steering requirement, or a combination of both.

‘Power steering requirement’ means the amount of hydraulic pressure required by the electro-hydraulic power steering system to provide the power steering assistance. The current power steering requirement is the amount of hydraulic pressure required by the electro-hydraulic power steering system at an instantaneous time to provide the required power steering assistance. The upcoming power steering requirement is the amount of hydraulic pressure required by the electro-hydraulic power steering system at a time in future, to provide the power steering assistance required at that time. Upcoming may mean a short time in the future, for example one or two seconds, or it may be a longer time in the future, for example minutes or hours, as will become clear from the examples described below.

The system 34 of FIG. 3 also includes a device 41, which is arranged to determine an operating characteristic of the vehicle so that the controller 40 can determine the power steering requirement.

The power steering requirement can vary during operation of the vehicle. For example, at low speeds the force required to move the steering rack 2 is greater than at higher speeds because of increased friction between the wheels 3 (see FIG. 1) and the road surface. Therefore, a greater power steering requirement exists, for example, when parking a vehicle, than when driving in a straight line.

As explained above, the controller 40 is configured to operate the motor 35, and therefore the pump 17, according to the power steering requirement of the vehicle. In particular, the controller 40 is configured to reduce the operating speed of the motor 35 in response to a decrease in the power steering requirement. Also, the controller 40 is configured to increase the operating speed of the motor 35 in response to an increase in the power steering requirement. A higher operating speed of the motor 35 will provide more hydraulic pressure than a low operating speed, and so an increase in the power steering requirement will lead to an increase in hydraulic pressure.

The controller 40 may stop the motor 35 altogether when there is zero power steering requirement. Alternatively, the controller 40 may run the motor 35 at a decreased speed to maintain a minimum amount of hydraulic pressure. The controller 40 may be configured to control the motor 35 so that the motor speed is directly proportional to the power steering requirement. Therefore, the motor speed is always sufficient to provide the required power steering assistance, but less energy is wasted compared to if the motor 35 is constantly at full speed.

In some examples, the controller 40 is configured so that the motor 35 is either stationary or at full speed, according to the power steering requirement. In other examples, the controller 40 is configured so that the motor 35 is either at an idling speed or at full speed, according to the power steering requirement.

By reducing the operating speed of the motor 35 at times when there is no or low power steering requirement, electric power can be saved compared to if the motor 35 were running at full speed all of the time. This results in improved efficiencies for conventional petrol/diesel powered vehicles, as less of the engine's power is given over to generating electrical power. It is also extremely advantageous for electrically driven and hybrid vehicles because it reduces use of electrical power by the motor at times when the power steering requirement is low, and can thereby increase the overall range of the electric vehicle.

As described above, the electro-hydraulic system 34 includes a device 41 that determines an operating characteristic of the vehicle.

In a first example, the device 41 comprises an angle sensor arranged to measure an angular position of the steering wheel 9 (see FIG. 1). In this example, the steering wheel 9 angle is the operating condition of the vehicle. The greater the angular position of the steering wheel 9 (see FIG. 1), the more power steering assistance is generally required for any further movement. In particular, the angular position of the steering wheel 9 (see FIG. 1) is measured from a position where the wheels 3 (see FIG. 1) are straight. Therefore, a measured angle indicates that the wheels 3 (see FIG. 1) are in a position for steering. The larger the angle, the more power steering assistance is likely to be required, at least to move the wheels back to the central position for driving in a straight line.

Therefore, in this example the power steering requirement is based on the angular position of the steering wheel 9 (see FIG. 1), and the controller 40 is configured to increase the operating speed of the motor 35 in response to an increased angular steering wheel position, and to decrease the operating speed of the motor 35 in response to a decreased angular steering wheel position.

In a further example, the controller 40 may be adapted to determine the rate of change of the angular position of the steering wheel 9 (see FIG. 1), i.e. the angular acceleration. In this example, the rate of movement of the steering wheel 9 is the operating condition of the vehicle. In this way, the power steering requirement is based on the angular acceleration of the steering wheel 9 (see FIG. 1), and the controller 40 is configured to control the operating speed of the motor 35 in according to this factor. In particular, the greater the determined angular acceleration, the more steering force is required to move the steering rack 2 and wheels 3 (see FIG. 1), and therefore the greater the power steering requirement is. Therefore, the controller 40 can be configured to increase the operating speed of the motor 35 in response to increased or increasing angular acceleration of the steering wheel 9 (see FIG. 1), and to decrease the operating speed of the motor 35 in response to decreased, or decreasing, angular acceleration of the steering wheel 9 (see FIG. 1).

In another example, the device 41 comprises a torque sensor that is arranged to determine the amount of torque being applied to the steering wheel 9 (see FIG. 1). In this example, the torque being applied to the steering wheel 9 is the operating condition of the vehicle. The determined torque indicates the speed and force with which the steering wheel 9 (see FIG. 1) is being turned, and the power steering requirement is based on this factor. Therefore, the controller 40 is configured to increase the speed of the motor 35 in response to an increase in torque, or decrease the speed of the motor 35 if the torque is zero or is decreased.

The controller 40 may be further adapted to determine the rate of change of the torque being applied to the steering wheel 9 (see FIG. 1). The power steering requirement can be based on the rate of change of the torque, and the controller 40 can be configured to control the operating speed of the motor 35 in according to this factor. If the measured torque is increasing then the controller 40 can be configured to increase the speed of the motor 35, and if the measured torque is decreasing, the controller 40 can be configured to decrease the speed of the motor 35.

In another example, the device 41 may comprise both an angle sensor and a torque sensor, and the power steering requirement may be based on a combination of any of the angular position of the steering wheel 9 (see FIG. 1), the angular acceleration of the steering wheel, the torque applied to the steering wheel, and the rate of change of torque being applied to the steering wheel.

In another example, the device 41 may include a sensor to determine the velocity of the vehicle. This sensor may be the speedometer of the vehicle, or may be an additional sensor. In this example, the speed of the vehicle is the operating condition of the vehicle.

Generally, greater steering force is required at lower vehicle velocity, as there is more friction between the wheels 3 (see FIG. 1) and the road surface when turning, and because greater steering angles (and therefore greater movement of the steering rack) are more likely to be required at lower velocity. Therefore, at lower velocity the power steering requirement is higher, and the controller 40 can be configured to increase the operating speed of the motor 35. At higher velocity the power steering requirement is lower, and the controller 40 can be configured to decrease the operating speed of the motor 35. The controller 40 can be configured to increase the operating speed of the motor 35 in response to decreasing velocity, and to decrease the operating speed of the motor 35 in response to increasing velocity.

In a further example, the device 41 includes a sensor arranged to determine the load of the vehicle. In this example, the load of the vehicle is the operating condition of the vehicle.

In particular, the sensor may include a pressure transducer or other pressure sensor to determine the magnitude of the vehicle load through the pressure being applied through at least a part of the chassis of the vehicle. Alternatively, the sensor may be a displacement sensor arranged to determine a rest position of the suspension system of the vehicle. A higher vehicle load will lead to a more compressed rest position for the suspension system, allowing the device 41 to determine an indicative vehicle load.

Generally, a higher vehicle load will lead to a greater power steering requirement, as there is increased friction between the wheels 3 (see FIG. 1) and the road surface during turning. Therefore, if the determined vehicle load is increased, the power steering requirement is also increased, and the controller 40 can operate the motor 35 at a higher speed. Conversely, if the vehicle load is decreased, then the power steering requirement is also decreased, and the controller 40 can be configured to reduce the operating speed of the motor 35.

In another example, the device 41 includes a sensor arranged to determine the type pressures of the vehicle. In this example, the tyre pressures are the operating condition of the vehicle.

In particular, the sensor may include a pressure transducer or other pressure sensor arranged to determine the tyre pressures. Lower tyre pressures will increase the contact surface area between the tyres and the road, and therefore increase the power steering requirement. Conversely, higher tyre pressures will decrease the contact surface area between the tyres and the road, and therefore decrease the power steering requirement. The controller 40 may therefore be configured to control the operating speed of the motor 35 according to the power steering requirement determined from the tyre pressures.

In another example, the device 41 includes a vehicle-location device to determine the location of the vehicle. The device 41 may include, for example a positioning system, in particular a satellite positioning system such as a GPS device, or similar, or a device for determining location based on local WiFi connections. In such examples, the location of the vehicle is the operating condition of the vehicle.

The location of the vehicle can be used to determine a power steering requirement for the vehicle. For example, when a vehicle is in a car park or on smaller urban roads more power steering assistance is likely to be required and so the power steering requirement is increased, and the controller can be configured to increase the operational speed of the motor 35 accordingly. On the other hand, if the vehicle is on a long straight road, then a lower level of power steering assistance is likely to be required, the power steering requirement is therefore lowered and the controller can be configured to decrease the operational speed of the motor 35 accordingly.

In another example, the device 41 includes a vehicle-navigation device that presents a route to the driver of the vehicle, and may optionally also calculate that route based on a desired destination input by the driver. In such examples, the route of the vehicle, and the position of the vehicle along the route, are the operating conditions of the vehicle.

In examples, the device 41 may include a satellite navigation device, such as a GPS device or similar. The navigation device may calculate the desired route for the vehicle, or may simply display a pre-programmed route.

In this example, the power steering requirement can be based on the route of the vehicle, and so the controller 40 can be configured to alter the operational speed of the motor 35 in accordance with the planned route and the varying power steering requirement along that route.

By knowing the route, the controller 40 is informed of the number of turns and junctions, the type of roads, the speed limits of the roads, and various other factors that influence the power steering requirement, and can determine the power steering requirement along the route.

Additionally, the vehicle-navigation device may provide information on traffic, road works and other live information, and so the controller 40 can take these factors into account when determining the power steering requirement for the route.

In another example, where the vehicle is a delivery vehicle it is also possible to include information on the loading and unloading locations of the route, and to factor in the changes in the power steering requirement based on the changing vehicle load before and after each loading / unloading location.

In other examples, if the location of the vehicle is a known depot, for example for delivery vehicles, then the determined power steering requirement can be increased as it is likely that steering power will be required.

In other examples, the system may have a maintenance mode, for example when the vehicle enters a garage. In such a maintenance mode the power steering requirement may be increased to account for the slow movement and higher steering forces required.

In some examples, the controller 40 is configured to constantly determine the power steering requirement of the vehicle during use. In this way, the power steering requirement is always based on the current operating conditions of the vehicle.

The controller 40 may also include a memory, and the memory may be used to store information on the power steering requirement associated with particular operating conditions of the vehicle. For example, the power steering requirement at a particular location may be stored in the memory, and the next time the vehicle is at this location the controller 40 already knows the power steering requirement. Similar information can be stored for all of the operating conditions described previously.

Additionally, power steering requirement information may be shared with other vehicles, for example via a cloud server or by making periodic updates to the memory. This would be particularly effective for a fleet of vehicles, for example a fleet of delivery vehicles. For delivery vehicles the transfer of information from one vehicle to another (optionally via a server) may take place in a depot.

In some examples, as explained above, the controller 40 is configured to determine the current power steering requirement of the vehicle and to control the motor 35 and pump 17 accordingly.

In other examples, the controller 40 is configured determine an upcoming power steering requirement, and to control the motor 35 and pump 17 accordingly. For example, in examples when the device 41 includes a vehicle-navigation device the controller 40 is able to anticipate the power steering requirement of a particular turn at a time before the vehicle reaches that turn, and thus can adjust the speed of the motor 35 in good time before reaching the turn.

In other examples, the controller 40 predicts an upcoming power steering requirement based on the operating conditions of the vehicle. In this way, the controller 40 can be configured to increase and decrease the operational speed of the motor 35 before the vehicle reaches the point at which power steering is required.

In some cases, the motor 35 will have a ramp-up time, which is the time between the controller 40 increasing power to the motor 35 and the time that the motor 35 reaches the desired operational speed. This results in a lag before the pump 17 is providing the hydraulic pressure required for the steering assistance.

Location information, obtained from a location device, can be used to predict an upcoming power steering requirement. For example, if the vehicle is in a car park then there is likely to be significant power steering requirement until the vehicle leaves the car park. On the other hand, if the vehicle is on a motorway the power steering requirement is likely to be relatively low for long periods of time, until the vehicle is leaving the motorway, and then the power steering requirement is likely to increase.

Navigation information, provided by a navigation device, can also be used to predict an upcoming power steering requirement. For example, if the navigation device indicates an upcoming turn, the controller 40 can predict the power steering requirement for that turn and increase the speed of the motor 35 before the vehicle reaches the turn, in order to account for the ramp-up time of the motor 35.

It will be appreciated that the device 41 may include any one or any combination of the above types of sensors and devices, so that the power steering requirement can be based on any one or combination of the factors measured by the above example devices 41, and the controller 40 can therefore increase and decrease the operational speed of the motor 35 according to any one or combination of these factors.

In particular, the controller 40 may determine both the current power steering requirement and the upcoming power steering requirement at any given time, and control the speed of the motor 35 (and therefore the pump 17) according to the greater power steering requirement, to ensure that there is always adequate hydraulic pressure for steering assistance.

In the example shown in FIG. 4, the electro-hydraulic system 34 has all of the same components as the electro-hydraulic system 34 described with reference to FIG. 3, particularly the pump 17, motor 35, power steering box 16, hydraulic ram 15, controller 40 and device 41. In FIG. 4, hydraulic pipes are shown in solid lines, while electrical connections are shown in dotted lines.

In this example, the electro-hydraulic system 34 further includes an accumulator 42.

The accumulator 42 is connected to the pipe 37 that connects the outlet of the pump 17 to the inlet 18 of the power steering box 16. That is, the accumulator 42 is connected to the high pressure side of the hydraulic system. A valve 43 is provided between the accumulator 42 and the pipe 37, so that fluid flow between the accumulator 42 and the pipe 37 is controlled by the valve 43.

The accumulator 42 is preferably a gas-envelope type hydraulic accumulator, also called a compressed gas or gas-charged closed accumulator, where the hydraulic fluid compresses a volume of gas within the accumulator, which provides hydraulic pressure. The accumulator 42 may include an elastic diaphragm that separates the hydraulic fluid from the gas, or an entirely enclosed bladder containing the gas, or a floating piston, or a metal bellows. Alternatively, the accumulator 42 may be a spring type accumulator, with a spring acting on the hydraulic fluid to provide hydraulic pressure.

The valve 43 is preferably a solenoid valve. The solenoid valve may have a single solenoid or a double solenoid. If spring loaded, the normal position may be open or closed. Alternatively, the valve 43 may be any other type of valve that can be controlled to close off or open the connection between the accumulator 42 and the pipe 37. The valve 43 may be integrated into the accumulator 42 or the valve 43 may be separate to the accumulator 42.

The condition of the valve 43, either open or closed, is controlled by the controller 40.

The accumulator 42 also includes a pressure transducer 44 arranged to measure the hydraulic pressure within the accumulator 42.

A check valve (a one-way valve) 45 is arranged in the pipe 37 between the pump 17 and the connection to the accumulator 42. The check valve 45 is arranged to permit flow of hydraulic fluid from the pump 17 towards the power steering box 16, and to prevent flow of hydraulic fluid from the power steering box 16 towards the pump 17.

The accumulator 42 is charged with hydraulic fluid by opening the valve 43 when the pump 17 is operational, which allows hydraulic fluid to be pumped to the power steering box 16 and also into the accumulator 42.

Once charged, the valve 43 is closed to isolate the fluid in the accumulator 42 from the pipe 37, and therefore also isolate the fluid in the accumulator 42 from the pump 17 and the power steering box 16.

In one example, the valve 43 is closed when the pressure transducer 44 indicates that the pressure in the accumulator 42 has reached a predetermined value. Alternatively, if no pressure transducer 44 is provided, the controller 40 closes the valve 43 after a set amount of time when the motor 35 is operational and the valve 43 is open, and that time can be determined to ensure that the accumulator 42 has reached the appropriate pressure.

When the valve 43 is closed, hydraulic pressure generated by the pump 17 passes through the pipe 37 to the power steering box 16, and then to the hydraulic ram 15, to provide power assistance for the steering.

As explained previously, at certain times during operation of a vehicle the motor 35 and pump 17 will be slowed down, or may be stopped altogether, particularly when there is decreasing, little, or no, power steering requirement. This has the benefit of saving significant amounts of energy.

However, one result of this arrangement is that there is a time lag between the controller 40 sending a signal to increase the speed of the motor 35 (and therefore the pump 17) and the associated increase of hydraulic pressure generated by the pump 17. This is primarily caused by the time lag as the speed of the motor 35 is ramped-up.

The hydraulic pressure in the accumulator 42 can be released into the pipe 37 at times when the power steering requirement has increased, or is predicted to increase, but the motor 35 and pump 17 are not operating at a speed that is sufficient to provide the required hydraulic pressure. In particular, the hydraulic pressure in the accumulator 42 can be released into the pipe 37, and therefore into the steering box 16, during the time that the motor 35 ramps-up. In this way, the accumulator 42 ensures that there is always adequate hydraulic power available for power steering assistance, even if the motor 35 is slowed or stopped at a time when the power steering requirement increases.

When the valve 43 is opened to release the hydraulic pressure from the accumulator 42 into the pipe 37, the check valve 45 prevents the hydraulic fluid flowing back towards the pump 17. Therefore, the hydraulic fluid flows towards, and into, the power steering box 16 and the hydraulic ram 15.

In addition, the check valve 45 will remain closed until the pressure generated by the pump 17 on the pump side of the check valve 45 exceeds the pressure on the accumulator 42 side of the check valve 45. Once this occurs, the pump 17 will provide hydraulic pressure to the power steering box 16, and at the same time will recharge the accumulator 42.

The controller 40 only closes the valve 43 once the accumulator 42 is recharged. As previously explained, the valve 43 may be closed after the pressure transducer 44 detects adequate pressure, or the valve 43 may be closed after a predetermined period of time that allows the accumulator 42 to be recharged.

In the above described embodiments, under normal running circumstances the pump 17 will provide hydraulic pressure to the power steering box 16 and hydraulic ram 15. If the accumulator 42 is being charged, then the pump 42 charges the accumulator 42 while also providing hydraulic pressure for the power steering box 16 (i.e. the valve 43 is open). If the accumulator 42 is already charged, then the pump 17 only provides hydraulic pressure to the power steering box 16 (i.e. the valve 43 is closed). The valve 43 can be opened, to release the hydraulic fluid from the accumulator 42, when the speed of the pump 17 is insufficient to generate the required power steering assistance, for example, during the ramp-up time of the motor 35.

The controller 40 is configured to operate the valve 43 according to the power steering requirement. The power steering requirement may be determined from the measurements of a device 41, in the same way as the previously described examples. In particular, the device 41 may include any of the previously described alternatives, such as a steering wheel angle sensor, a steering wheel torque sensor, a vehicle velocity sensor, a vehicle load sensor, a vehicle-location device, or a vehicle-navigation device. The power steering requirement may be a current power steering requirement, or it may be an upcoming power steering requirement that may be predicted, as previously described.

In examples where the device 41 determines a current power steering requirement and the controller 40 controls the speed of the motor 35 accordingly, the accumulator 42 can be opened to provide hydraulic pressure as the speed of the motor 35 is ramped up following an increase in the power steering requirement.

In examples where the device 41 predicts upcoming power steering requirement and the controller 40 controls the speed of the motor 35 accordingly, in particular where the device 41 comprises a vehicle-location and/or navigation device, the accumulator 42 can be opened to provide hydraulic pressure in response to an unexpected (i.e. not predicted) increase in power steering requirement. This may happen, for example, if the driver takes a detour from the planned route, or has to take sudden steering action.

In all of the above-described examples, the accumulator 42 can be opened to provide hydraulic pressure when the hydraulic pressure being provided by the motor 35 and pump 17 is insufficient for the determined power steering requirement. The controller 40 can determine the appropriate conditions for opening the valve 43 based on the speed of the motor 35 and the power steering requirement.

As illustrated in FIG. 5, the method of controlling the electro-hydraulic steering system includes the following steps:

1. determining a power steering requirement of the electric vehicle, 46;
2. controlling the speed of the motor 35, and therefore the speed of the pump 17, according to the power steering requirement, 47; and,
3. opening the valve 43 in response to an increase in the power steering requirement, 48.

The method may also include the step of closing the valve 43 once the accumulator 42 has been recharged.

As previously explained, the step of determining a power steering requirement of the electric vehicle may include determining a current power steering requirement, and/or it may include determining and/or predicting an upcoming power steering requirement. The power steering requirement may be based on the measurements of a device 41, such as those previously described.

Embodiments of the present invention may be implemented in software, hardware, application logic or a combination of software, hardware, and application logic. The software, application logic and/or hardware may reside on memory, or any computer media. In an example embodiment, the application software or an instruction set is maintained on any one of various conventional computer-readable media. In the context of this document, a “memory” or “computer-readable medium” may be any media or means that can contain, store, communicate, propagate or transport the instructions for use by or in connection with an instruction execution system, apparatus, or device, such as a computer.

In order to address various issues and advance the art, the entirety of this disclosure shows by way of illustration various embodiments in which the claimed invention(s) may be practiced and provide for a superior electro-hydraulic power steering system. The advantages and features of the disclosure are of a representative sample of embodiments only, and are not exhaustive and/or exclusive. They are presented only to assist in understanding and teach the claimed features. It is to be understood that advantages, embodiments, examples, functions, features, structures, and/or other aspects of the disclosure are not to be considered limitations on the disclosure as defined by the claims or limitations on equivalents to the claims, and that other embodiments may be utilised and modifications may be made without departing from the scope and/or spirit of the disclosure. Various embodiments may suitably comprise, consist of, or consist essentially of, various combinations of the disclosed elements, components, features, parts, steps, means, etc. In addition, the disclosure includes other inventions not presently claimed, but which may be claimed in future.

Claims

1. An electro-hydraulic power steering system for an electric vehicle, the system comprising:

a hydraulic actuator arranged to act on a steering rack of said electric vehicle;

a pump adapted to provide hydraulic pressure to the hydraulic actuator via a pipe;

an accumulator connected to the pipe and arranged to hold hydraulic fluid under pressure;

a valve arranged between the accumulator and the pipe such that, during use, when the valve is closed the accumulator is isolated from the pipe and hydraulic fluid from the pump is provided to the hydraulic actuator via the pipe, and when the valve is open hydraulic fluid held in the accumulator is provided to the hydraulic actuator via the pipe; and,

a controller configured to determine a power steering requirement of said electric vehicle;

and wherein the controller is configured to control operation of the pump according to the determined power steering requirement.

2. The electro-hydraulic power steering system of claim 1, wherein the controller is further configured to control the valve.

3. The electro-hydraulic power steering system of claim 1 or claim 2, further comprising a device adapted to determine an operating characteristic of said vehicle, and wherein the controller is configured to determine the power steering requirement of said electric vehicle according to said operating characteristic.

4. The electro-hydraulic power steering system of claim 3, wherein the controller is configured to determine a current power steering requirement of said electric vehicle.

5. The electro-hydraulic power steering system of claim 3 or claim 4, wherein the controller is configured to predict an upcoming power steering requirement of said electric vehicle.

6. The electro-hydraulic power steering system of any of claim 3 to 5, wherein the device comprises a sensor adapted to measure a parameter associated with a steering wheel of said electric vehicle.

7. The electro-hydraulic power steering system of claim 6, wherein the device comprises a steering wheel angle sensor.

8. The electro-hydraulic power steering system of claim 6 or claim 7, wherein the device comprises a steering wheel torque sensor.

9. The electro-hydraulic power steering system of any of claims 3 to 8, wherein the device comprises a vehicle speed sensor.

10. The electro-hydraulic power steering system of any of claims 3 to 9, wherein the device comprises a vehicle-location device for determining a location of said electric vehicle.

11. The electro-hydraulic power steering system of any of claims 3 to 10, wherein the device comprises a vehicle-navigation device for displaying and/or planning a route for said electric vehicle.

12. The electro-hydraulic power steering system of any preceding claim, wherein the controller is configured to reduce the operating speed of the pump in response to a reduction in the power steering requirement, and to increase the operating speed of the pump in response to an increase in the power steering requirement.

13. The electro-hydraulic power steering system of any of claims 2 to 12, wherein the controller is configured to open the valve in response to an increase in the power steering requirement.

14. The electro-hydraulic power steering system of any preceding claim, further comprising a pressure sensor arranged to measure a pressure within the accumulator.

15. The electro-hydraulic power steering system of claim 14, wherein the controller is configured to open the valve for recharging the accumulator.

16. The electro-hydraulic power steering system of claim 14 or claim 15, wherein the controller is configured to close the valve when the pressure within the accumulator reaches a predetermined value.

17. The electro-hydraulic power steering system of any of claims 14 to 16, wherein the controller is configured to operate the pump when the pressure within the accumulator is below a predetermined value.

18. The electro-hydraulic power steering system of any preceding claim, further comprising a check valve disposed in the pipe between the pump and the connection to the accumulator.

19. The electro-hydraulic power steering system of any preceding claim, wherein the hydraulic actuator comprises a power steering box, and a hydraulic ram arranged to act on said steering rack.

20. An electric vehicle comprising the electro-hydraulic power steering system of any preceding claim.

21. A controller for an electro-hydraulic power steering system for an electric vehicle, the steering system comprising:

a hydraulic actuator arranged to act on a steering rack of said electric vehicle;

a pump adapted to provide hydraulic pressure to the hydraulic actuator via a pipe;

an accumulator connected to the pipe and arranged to hold hydraulic fluid under pressure; and,

a valve arranged between the accumulator and the pipe such that, during use, when the valve is closed the accumulator is isolated from the pipe and hydraulic fluid from the pump is provided to the hydraulic actuator via the pipe, and when the valve is open hydraulic fluid held in the accumulator is provided to the hydraulic actuator via the pipe;

wherein the controller is configured determine a power steering requirement of said electric vehicle and the controller is configured to control operation of the pump according to the power steering requirement.

22. The controller of claim 21, wherein the controller is further configured to open the valve in response to an increase in the power steering requirement.

23. The controller of claim 21 or claim 22, wherein the controller is configured to reduce the operating speed of the pump in response to a reduction in the power steering requirement, and to increase the operating speed of the pump in response to an increase in the power steering requirement.

24. The controller of claim 23, wherein the controller is configured to open the valve if the operating speed of the pump is insufficient for the determined power steering requirement.

25. The controller of any of claims 21 to 24, wherein the controller is configured to determine a current power steering requirement of said electric vehicle.

26. The controller of any of claims 21 to 25, wherein the controller is configured to predict an upcoming power steering requirement of said electric vehicle.

27. The controller of any of claims 21 to 26, wherein the electro-hydraulic power steering system further comprises a pressure sensor arranged to measure a pressure within the accumulator.

28. The controller of claim 27, wherein the controller is configured to open the valve for recharging the accumulator.

29. The controller of claim 28, wherein the controller is configured to close the valve when the pressure within the accumulator reaches a predetermined value.

30. The controller of any of claims 27 to 29, wherein the controller is configured to operate the pump when the pressure within the accumulator is below a predetermined value.

31. A method of controlling an electro-hydraulic power steering system for an electric vehicle, the steering system comprising:

a hydraulic actuator arranged to act on a steering rack of said electric vehicle;

a pump adapted to provide hydraulic pressure to the hydraulic actuator via a pipe;

an accumulator connected to the pipe and arranged to hold hydraulic fluid under pressure;

a valve arranged between the accumulator and the pipe such that, during use, when the valve is closed the accumulator is isolated from the pipe and hydraulic fluid from the pump is provided to the hydraulic actuator via the pipe, and when the valve is open hydraulic fluid held in the accumulator is provided to the hydraulic actuator via the pipe; comprising the steps of:

determining a power steering requirement of said electric vehicle; and,

controlling operation of the pump according to the determined power steering requirement.

32. The method of claim 31, further comprising the step of opening the valve in response to an increase in the power steering requirement.

33. The method of claim 31 or claim 32, further comprising the steps of reducing the operating speed of the pump in response to a reduction in the power steering requirement, and increasing the operating speed of the pump in response to an increase in the power steering requirement.

34. The method of claim 33, further comprising the steps of determining whether the operating speed of the pump is sufficient for the determined power steering requirement; and, opening the valve if the operating speed of the pump is insufficient for the determined power steering requirement.

35. The method of any of claims 31 to 34, wherein the step of determining a power steering requirement of said electric vehicle comprises determining a current power steering requirement.

36. The method of any of claims 31 to 35, wherein the step of determining a power steering requirement of said electric vehicle comprises predicting an upcoming power steering requirement.

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37. The method of any of claims 31 to 36, further comprising the steps of measuring pressure within the accumulator, and closing the valve when the pressure within the accumulator reaches a threshold.

38. Apparatus comprising means for performing a method according to any of claims 31 to 37.

39. Computer-readable instructions which, when executed by computing apparatus, cause the computing apparatus to perform a method according to any of claims 31 to 37.