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WO-A1-2018/059727
DE-A1-102007 031 429

Control device

The invention relates to a control device for a hydraulic consumer that is susceptible to vibrations with the features described in the preamble of claim 1.

In practice, such control devices are frequently used to control slewing gear for cranes or excavators, for example. These types of slewing gear often have a hydraulic motor which can be driven in two opposite directions of rotation to rotate the crane or excavator structure into a required direction or position.

The control devices of the prior art display a disadvantageous response. If the control spool of these control devices suddenly opens or closes, this causes a control response, in conjunction with the pressure compensator, which corresponds to a PT-2 element in control technology terms. This means that vibrations are generated in the volume flow of the hydraulic fluid which are then damped by the control device. These vibrations are relayed to the consumer, thus forming torsional vibrations which can make the consumer difficult to control. Under some circumstances, this can lead to damage to the consumer.

WO 2017/092855 A1 describes a control device for a hydraulic consumer that is susceptible to vibrations comprising a valve with a control spool that can be controlled using an actuating device, the valve comprising a pressure supply port to which a pressure compensator can be connected, said pressure compensator being able to be supplied with pressurised fluid by a pressure supply apparatus, the actuating device comprising a motor, and a load-pressure dependent force being able to be generated at the control spool by means of a control device.

DE 10 2007 031 429 A1 and WO 2018/059727 A1 disclose further control devices.

The object of the invention is therefore to disclose an improved control device which comprises a greatly reduced PT-2 response or such a response reduced to the maximum extent.

This object is achieved by a control device with the features described in claim 1.

According to the characterising part of claim 1, it is provided that the load pressure-dependent force at the control spool acts on an electric motor control system of the DC motor, which detects a change in the force and serves to damp the vibrations of the consumer, counteracting this change in force.

In the solution according to the invention, a force is applied to the control spool by the load pressure, said force being transmitted to the motor, which evaluates this force and then moves the control spool in consideration of this force. In this process, the load pressure is recorded directly in such a way that any vibrations that arise are effectively damped or even compensated by the motor and the control system for the control spool. By using the control device according to the invention, it is possible to avoid using a plurality of pressure sensors to record the load pressure in the flow and return. Furthermore, this is a particularly low-wear solution and therefore has a particularly long service life and is cost-effective because there is no need to fit and maintain any additional components.

In an advantageous embodiment of the invention, a rotation angle sensor is assigned to the motor control system, said sensor preferably comprising a Hall sensor fixed to the housing and a rotatable magnet fixed to a motor shaft of the DC motor. A rotation of the motor shaft which is proportional to the displacement of the control spool can therefore be evaluated and relayed to a motor control system which then controls the motor accordingly.

In an advantageous embodiment of the invention, the control device comprises a DC motor in the form of a brushless DC motor (or EC motor) with sensorless commutation, which makes it possible to record a rotor position of the DC motor corresponding to the effective load pressure-dependent force at the control spool by means of a countervoltage caused in the coils of a stator, which can be evaluated by the motor control system. As a result of sensorless commutation, the pressure forces at the control spool are effectively transmitted to the DC motor, where they can be evaluated to determine the rotor position in a simple manner.

The DC motor may, below a pre-definable minimum speed, especially at standstill, experience current pulses at its coils by means of the motor control system, said pulses leaving the DC motor at standstill, but still influencing the magnetic field of the rotor, as a result of which the current flow through the coils can be changed due to the change in the load pressure-dependent force such that it is possible to determine the rotor position, which allows the position of the control spool to be adjusted as the end result. In this case, it is particularly advantageous that the disclosed solution also allows the rotor position to be determined reliably even at particularly low rotor speeds.

The DC motor preferably moves the control spool, which is guided such that it can be displaced longitudinally in a valve housing of the valve, by means of a gearwheel mechanism. The gearwheel mechanism provides a directly proportional relationship between the axial position of the control spool and the angle of rotation of the rotor. This relationship is used both to record the load pressure-dependent force and to position the control spool.

The hydraulic consumer may be a hydraulic motor with two opposite directions of rotation.

The pressure supply apparatus is advantageously an LS-pressure-regulated phase shift angle pump, which can be controlled by the valve. In this manner, the power of the pressure supply apparatus can be adjusted to the respective requirements of the user.

The valve housing may comprise a pressure supply port, at least two service ports, which are exposed alternately to a load pressure or a return pressure, and a return port.

It is particularly advantageous that the control spool, in its neutral or middle position in the valve housing, as part of the control device, blocks two signal lines, which, in displacement positions of the control spool outside the neutral or middle position, relay the load pressure to a first control side and the return pressure to an opposite, second control side of the control spool. This thus ensures that, in the neutral position, the control spool cannot be displaced by the pressures present at the service ports, while the load pressure is reliably relayed to the control sides of the control spool and thus to the motor control system of the DC motor for each position in which the control spool is deflected from the neutral position. As the pressure at the pressure supply port is always only minimally higher than the load pressure at the service port that is subjected to pressure, the control spool can, on one of its control sides, also, by way of simplification, be subjected to the pressure at the pressure supply port which is representative of the load pressure.

A diaphragm may be connected in each of the two signal lines. The diaphragm causes the pressure to be reported reliably to the control sides, on the one hand, and, on the other hand, prevents excessive leakage. A further purpose of the diaphragms is to help damp the movements of the control spool.

Both control sides of the control spool are advantageously guided in control chambers of the valve housing, which are each connected to a tank or other return by means of a return diaphragm. It is possible to relieve the pressure by connecting the control chambers to the tank, making it easier to move the control spool in the valve housing.

The invention is explained in greater detail below with reference to an embodiment shown in the drawings, in which:

Fig. 1 is a schematic representation of a circuit diagram of a hydraulic system according to the prior art with a valve;

Fig. 2 is a longitudinal section through a valve according to the invention, which is shown in a neutral position;

Fig. 3 is a longitudinal section through the valve in Fig. 2, in which the control spool is displaced into an end position;

Fig. 4 shows the valve from Fig. 3, with the control spool shown in a sectional view;

Fig. 5 is an enlarged view of detail X in Fig. 4; and

Fig. 6 is an enlarged view of detail Y in Fig. 4.

Fig. 1 is a schematic representation of a hydraulic system 10 according to the prior art with a control device 12. A pressure supply apparatus 16 in the form of a pump sucks a pressurised fluid, in particular a hydraulic fluid, from a tank 14 and conveys this to a pressure compensator 20. As a function of the load pressure of a consumer 22, the pressure compensator 20 adjusts the pressure supply to a valve 23 connected in series with the control device 12. The consumer 22, consisting of a hydraulic motor 26 and a mass 28, is driven by the valve 23. The hydraulic motor 26 forms part of a slewing gear 30, which can be driven in two opposite directions of rotation in order to move the mass 28 into required rotation positions or to drive it at a required rotation speed. Capacities 36, 38, especially in the form of hydraulic accumulators, can be connected to connecting lines 32, 34 between the valve 23 and the hydraulic motor 26.

The valve 23 is a 4/3-way valve. The control spool 40 thereof is centred in a neutral or middle position 44 by a spring arrangement 42 and can be moved between its switching positions 44, 48, 50 by an actuating device 46. In addition to a pressure supply port B, the service ports A, B and the tank port T, the valve 23 also comprises a tap for the load pressure LS in order to relay said pressure to the pressure compensator 20 and to the pressure supply apparatus 16.

The pressure compensator 20 is connected in front of the valve 23. Said pressure compensator has three switching positions 52, 54, 56. In one switching position 52, shown on the right in the image plane, the connection from the pressure supply apparatus 16 to the valve 23 is interrupted. The pump pressure is relayed to a control side 60 of the pressure compensator 23 by means of a pressure compensator diaphragm 58 and counteracts a return spring 62 and, where applicable, a load pressure relayed from the valve 23. In the middle position 54 of the pressure compensator 20, the valve 23 is connected to the pressure supply apparatus 16 and a pressure present at the pressure supply port P of the valve 23 is relayed to the left-hand control side 60 of the pressure compensator 20 by means of the pressure compensator diaphragm 58. In a left-hand switching position 56, the fluid connection between the pressure supply apparatus 16 and the valve 23 is again interrupted, however the pressure present at the pressure supply port P of the valve 23 is still relayed to the left-hand control side 60 of the pressure compensator 20.

The valve 24 according to the invention is now explained with reference to Fig. 2, said valve replacing the valve 23 of the prior art. The valve 24 is an LS directional control valve in the

form of a slide valve. The design of the valve housing 64 with the associated control spool 40 corresponds to the fullest extent possible, in the embodiment shown in the figures, to the valve device known from DE 10 2013 021 317 A1, which is referred to. The invention is different in that the control spool 40 is provided with a control device 66 with special signal lines 68, 70 and an electric motor actuator 72 in the form of a brushless DC motor 74, the design of said motor making it possible to use the device 12 according to the invention particularly advantageously in series applications of valve blocks with valve devices positioned close together side by side. Where the terms “top side” and “bottom side” are used in this application, these terms refer to a normal installation position as shown in the figures.

In accordance with the solution disclosed in DE 10 2013 021 317 A1, the control spool 40 can be displaced along an axis 76 in the valve housing 64. The valve housing 64 comprises longitudinal sides and end sides 82, 84 which are opposite one another in pairs, but not shown. Furthermore, the valve housing 64 has a top side 86 and a bottom side 88. According to the illustration in Fig.2, the corresponding housing walls 90 are shown as broken. It is evident that the corresponding sides 82-88 may protrude in planes running plane-parallel in all directions. Housing connections such as a pressure supply port P, two service ports A, B, a return port and a load pressure port are also located on the valve housing 64, as is customary in such valve devices. The ports P, A, B, which are regularly installed in the form of holes in the valve housing 92, 94, 96 have longitudinal axes 98, 100, 102, which are reproduced as dashed lines.

The spring arrangement 42 located in the left-hand end region 104 of the housing provides a neutral or middle position 44 for the control spool 40 in a manner that is customary for such valves, as shown in Fig. 2. At the end opposite the left-hand housing region 104, as shown on the right-hand side in Fig. 2, a housing end part 106 is connected to the valve housing 64, said housing end part containing an inner chamber 108 which extends coaxially with respect to the axis 76, said chamber being sealed from the valve housing 64 via a seal 110, but still being regarded as part of the valve housing 64. In accordance with the valve device known from DE 10 2013 021 317 A1, the control spool 40 extends with one end portion 112 into the chamber 108 and interacts inside the chamber 108 with an actuating part 114 of an emergency actuation system 116 and a stroke length restriction system 118 of the control spool 40. As the latter also corresponds to the solution with adjustment screws known from the document, there is no need for a more detailed description in this respect.

The brushless DC motor 74 serving as an actuator 72 is arranged on the housing end part 106 such that its motor shaft 120 intersects the displacement axis 76 of the control spool 40 vertically, a pinion 124 located at the end 122 of the motor shaft 120 being situated inside

the chamber 108. A toothed rack 126 is fixed to the end portion 112 of the control spool 40, said rack engaging with the pinion 124. Alternatively, a multi-stage, in particular two-stage, planetary gear or an eccentric spur gear could also be provided. The minimal or non-existent self-locking of the drive also means that the emergency manual actuation system 116 has an advantageously simple design. As in the above-mentioned known solution, the control spool 40 is mounted in the chamber 108 in a rotationally fixed manner such that the toothed rack 126 is always in contact with a guiding sliding element 128 during axial movements brought about by the pinion 124. A roller bearing or a roller could also be provided instead of the illustrated sliding element 128.

In the embodiment shown, the electric motor is provided in the form of a brushless DC motor 74. If the ratio between the dimensions of the diameter D and the height H is significantly less than 1.5, preferably less than 1, such a motor 74 provides a torque allowing for quick and safe valve actuation and, with its slim design, permits a close side-by-side arrangement of the valve 24 in valve blocks.

As also shown in Fig. 2, a drive shaft 130, or a motor housing 132 respectively, passes through the notional extension of the top side 86 of the valve housing 64. Furthermore, the drive shaft 130 of the electric motor 74 is aligned in parallel with the longitudinal axes 98-102 of the fluid ports P, A, B.

The inner chamber 108, which is sealed from the outside, is under oil from the valve housing 64 with the result that the gear arrangement 134 formed by the pinion 122, the toothed rack 126 and a sliding element, which is not shown in greater detail, also runs under oil. In this process, the seal from the motor housing 132 of the electric motor 74 is formed by a rotary seal 136 provided on the motor shaft 120.

The entire width of the valve device 12 is available for the diameter of the circular motor housing 132 in the direction of the side-by-side arrangement in a valve block. If the diameter of the DC motor 74 and the motor housing 132 is correspondingly small, it would also be possible to offset the motor shaft 122 with respect to the displacement axis 76 of the control spool with the result that the motor shaft 120 is perpendicular to the displacement axis 74, wherein the motor shaft 120 intersects the plane containing the displacement axis 76 as before.

The control spool 40 is provided with annular recesses 140, 142 in the regions of the service ports A and B. These annular recesses 140, 142 are restricted by opening edges 146, which comprise control grooves 148. A pressure distribution circuit 150 is also provided. The pressures present at the service ports A, B, i.e. the pressure of the flow V and the pressure of the return R, are replicated by the pressure distribution circuit 150 on opposite control

sides 152, 154 of the control spool 40 if the control spool 40 is outside its neutral position 44, see Fig. 3 and 4. To this end, two separate signal lines 68, 70 are provided in the control spool 40. Each signal line 68, 70 connects a service port A, B with an adjacent control side 152, 154. For this purpose, for each signal line 68, 70, a radial hole 156, 158 is provided between the annular recesses 140, 142 of the service ports A, B, said hole being positioned such that it is covered by the valve housing 64 when the control spool 40 is in a neutral or middle position 44, see Fig. 2. If the control spool 40 is located outside this neutral position 44, one of the radial holes 156 is connected to the service port A guiding the load pressure via the pressure supply port P and the other hole 158 is connected to the service port B guiding the return pressure, see Fig. 3 and 4. Each radial hole 156, 158 emerges via an axial hole 160, 162 in the control spool 40 into a control chamber on a control side 152, 154 of the control spool 40.

As can also be seen in Fig. 2, 4 and 5, two diaphragms 164, 168 are provided in the signal lines 68, 70 in the control spool 40. The diaphragms 164, 168 are identical and are in each case formed by a screw-in part 170, which is screwed into one of the radial holes 156, 158 from the outside. A fluid connection between the assigned service port A, B and the control sides 152, 154 of the control spool 40 can be established in such a way via the respective diaphragm 164, 168. The respective screw-in part 170 forms, with the wall 171 of the control spool 40, a fluid channel between at least two restrictive cross holes 172, 174 arranged on top of one another in the screw-in part. The respective transverse hole 172, 174 in the screw-in part is in each case connected to a longitudinal hole 176, 178 in the screw-in part 170, which holes, with their ends 180, 182 facing away from one another, on the one hand lead into the control channel 68, 160; 70, 162 in the control spool 40 and, on the other hand, as a function of the respective displacement position of this control spool, lead into the pressure supply port P or one of the service ports A, B.

The control chambers 184, 108 at the ends 186, 112 of the control spool 40 are in each case connected to a tank via return diaphragms 188, 190.

Fig. 3 and 4 show the valve 24 according to the invention with a control spool 40 displaced into its right-hand end position 48. In this position, the pressure supply port P is connected to the service port A. Accordingly, the pressure at the pressure supply port P is relayed to the left-hand control side 152 of the control spool 40 via the signal line 68 provided in the control spool 40. As is particularly evident from Fig. 4, a screw 192 of the spring arrangement 42 is screwed into the axial hole 160 of the signal line 68. The screw 192 also comprises an axial hole 194 to connect the axial hole 160 in the control spool 40 to the assigned control side 152.

The control spool 40 has a shoulder 196 at its right-hand end 122. So that the control sides 152, 154 at both ends 186, 112 of the control spool 40 have the same surface area to ensure that the control response of the control device 12 is the same in both actuation directions, a fluid connection 200 is created from the signal line 70 to the annular part 202 of the control side 156. This is shown in Fig. 4 and 6. The fluid connection 200 encompasses a transverse hole 204 of the control spool 40 and at least one, although two are illustrated, axial groove 206 of the control spool 40.

The operating principle behind the control device 12 according to the invention is explained below.

When the control spool 40 is in the neutral or middle position 44, the signal lines 68, 70 are separated from the service ports A, B by the valve housing 64, see Fig. 2. In this position 44, the pressures in the flow V and the return R are therefore not reproduced on the control sides 152, 154 of the control spool 40. Instead, the control sides 152, 154 of the control spool 40 are depressurised towards the tank T via the return diaphragms 188, 190. In this position, the DC motor 74 is not notified of the load pressure and therefore controls the control spool 40 independently of the load pressure.

When the control spool 40 is outside the neutral position 44, connections are created between the service ports A, B and the control sides 152, 154 via the signal lines 68, 70, see Fig. 3 and 4. In these cases, the pressure at the service ports A, B acts on the control sides 152, 154, the pressure in the feed V acting on the control spool 40 in such a way that it tries to move the control spool 40 in a direction opening the connection from the pressure supply port P to the assigned service port A; B to a maximum. In the case shown in Fig. 3 and 4, the control spool 40 is moved to the right by the DC motor 74. The fluid pressure of the flow V is therefore applied on the left-hand control side 152 of the control spool 40 and therefore exerts pressure on the control spool 40, likewise towards the right.

In an embodiment of the invention, the deflection of the control spool 40 via the toothed rack 126 and the pinion 124 is transmitted to the motor shaft 120 and the rotation of the motor shaft 120 is recorded by a rotation angle sensor 210 assigned to a motor control system 208. The rotation angle sensor 210 comprises a Hall sensor 212 fixed to the housing and a rotatable magnet 214 fixed to a motor shaft 120 of the motor 74. In this solution, a rotary movement of the motor shaft 120 is brought about by the load pressure, said movement being evaluated with the rotation angle sensor 210 and relayed to the motor control system 208, which then controls the motor 74 accordingly to move the control spool 40 in consideration of the load pressure.

In a further embodiment, the pressure force exerted on the control spool 40 via the toothed rack 126 and the pinion 124 is transmitted to the rotor of the DC motor 74 and generates electrical countervoltages in the coils of the stator with the result that the current flow through the coils is changed, this being evaluated by a motor control system 208 of the DC motor 74 and used to adjust the position of the control spool 40. In the solution according to the invention, a force is applied to the control spool by the load pressure, said force being transmitted to the DC motor 74, which evaluates this force and then moves the control spool in consideration of this force.

In this process, the load pressure is recorded directly in such a way that any vibrations that arise are effectively damped or even compensated by the DC motor 74 and the control system for the control spool 40. By using the control device 12 according to the invention, it is possible to avoid using a plurality of pressure sensors to record the load pressure in the flow V and return R. Furthermore, this is a particularly low-wear solution and therefore has a particularly long service life and is cost-effective because there is no need to fit and maintain any additional components.

Patentkrav

1. Styreindretning til en hydraulisk forbruger (22), der er sårbar over for svingninger, omfattende en ventil (24) med en styreskyder (40), der kan styres ved hjælp af en betjeningsindretning (46), hvor ventilen (24) har en trykforsyningstilslutning (P), hvortil der kan tilsluttes en dødvægtstestindretning (20), der kan forsynes med trykfluid fra en trykforsyningsindretning (16), hvor betjeningsindretningen (46) omfatter en jævnstrømsmotor (74), og hvor der ved hjælp af en styreindretning (66) på styreskyderen (40) kan genereres en belastningstrykafhængig kraft, **kendetegnet ved, at** denne kraft på styreskyderen (40) påvirker en elektronisk motorstyring (208) af jævnstrømsmotoren (74), der registrerer en ændring af kraften og modvirkende denne ændring af kraften tjener til at dæmpe forbrugerens (22) svingninger.

2. Styreindretning ifølge krav 1, **kendetegnet ved, at** der til motorstyringen (208) er tilordnet en drejevinkelsensor (210), der fortrinsvis omfatter en Hallsensor (212), der er fastmonteret i huset, og en drejelig magnet (214), der er fastgjort på en motoraksel (120) af jævnstrømsmotoren (74).

3. Styreindretning ifølge krav 1, **kendetegnet ved, at** jævnstrømsmotoren er en børstefri jævnstrømsmotor (74), der har en sensorfri kommutering, der muliggør en registrering af en rotorposition af jævnstrømsmotoren, der svarer til den belastningstrykafhængige kraft, som virker på styreskyderen (40), ved hjælp af en modspænding, der udløses i spolerne af dens stator, og som kan evalueres af motorstyringen (208).

4. Styreindretning ifølge krav 3, **kendetegnet ved, at** jævnstrømsmotoren (74) under sit forudbestemmelige minimumsomdrejningstal ved hjælp af motorstyringen (208) oplever, især korte, strømimpulser på sine spoler, der lader jævnstrømsmotoren (74) forblive i stilstand, men alligevel påvirker det magnetiske felt af dens rotor, hvorved strømflowet kan ændres ved hjælp af spolerne på en sådan måde, at en bestemmelse af rotorpositionen er mulig.

5. Styreindretning ifølge et af de foregående krav, **kendetegnet ved, at** jævnstrømsmotoren (74) bevæger styreskyderen (40), der føres længdeforskydeligt i et ventilhus (64) af ventilen (24), ved hjælp af et tandhjulsdrev (134).

6. Styreindretning ifølge et af de foregående krav, **kendetegnet ved, at** den hydrauliske forbruger (22) er en hydromotor (26) med to modsatte rotationsretninger.

7. Styreindretning ifølge et af de foregående krav, **kendetegnet ved, at** trykforsyningsindretningen (16) er en LS-trykreguleret drejevinkelpumpe, der kan styres ved hjælp af ventilen (24).

8. Styreindretning ifølge krav 5, **kendetegnet ved, at** ventilhuset (64) har en trykforsyningstilslutning (P), mindst to brugstilslutninger (A, B), der skiftevis udsættes for et belastningstryk eller et returløbstryk, og en returløbstilslutning (T).

9. Styreindretning ifølge krav 8, **kendetegnet ved, at** styreskyderen (40) i en neutral stilling eller mellemstilling (44) i ventilhuset (64) som en del af styreindretningen (66) spærrer to signalledninger (68, 70), der i bevægelsesstillinger (48, 30) af styreskyderen (40) uden for den neutrale stilling eller mellemstillingen (44) leder belastningstrykket videre til en styreside (152; 154) og returløbstrykket videre til en modsat beliggende styreside (152; 154) af styreskyderen (40).

10. Styreindretning ifølge krav 9, **kendetegnet ved, at** hver især en blænde (164, 168) er koblet ind i de to signalledninger (68, 70).

11. Styreindretning ifølge krav 9 eller 10, **kendetegnet ved, at** de to styresider (152, 154) er ført i styrerum (108, 184) af ventilhuset (64), der hver især via en returløbsblænde (188, 190) er tilsluttet til en tank (T) eller et andet returløb.

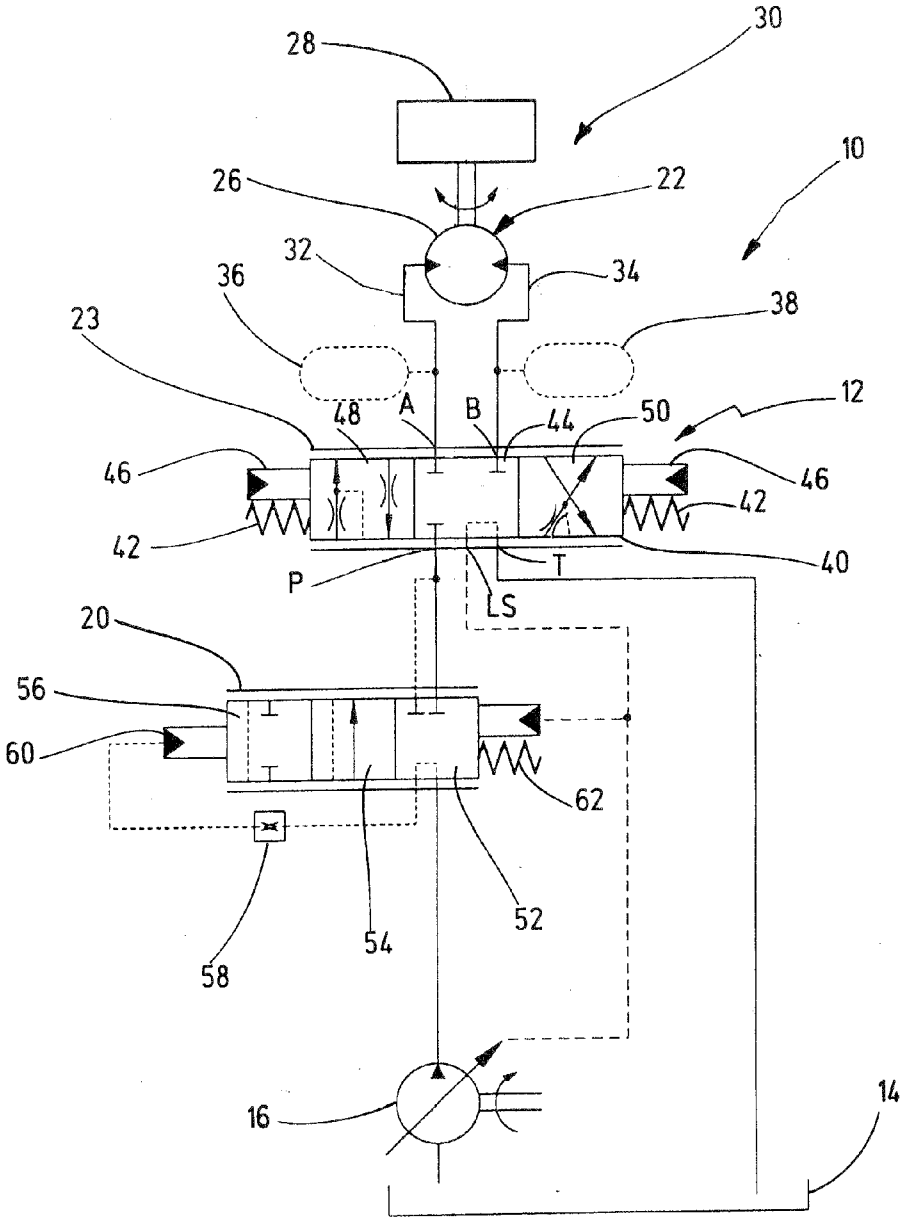
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Fig.1

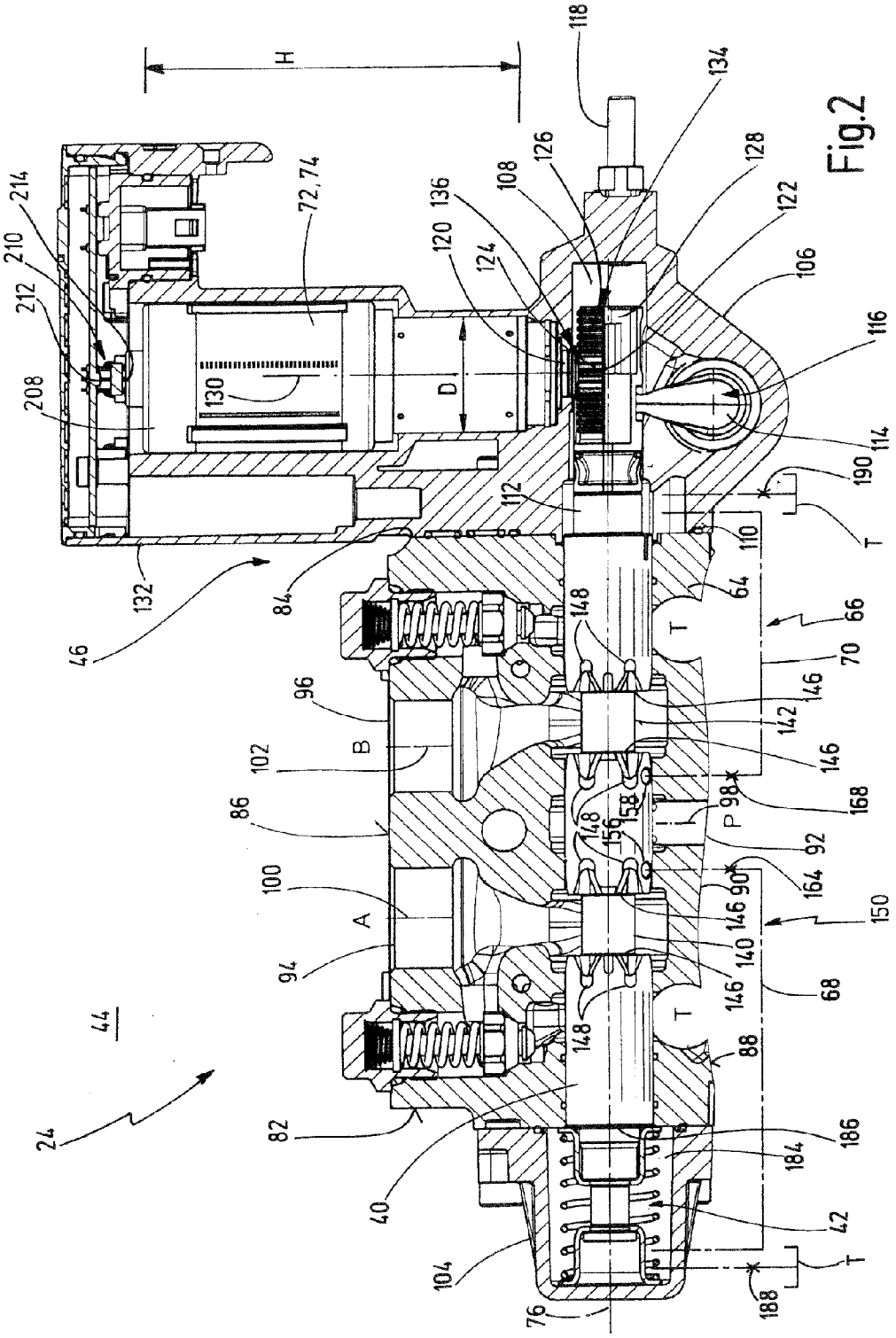
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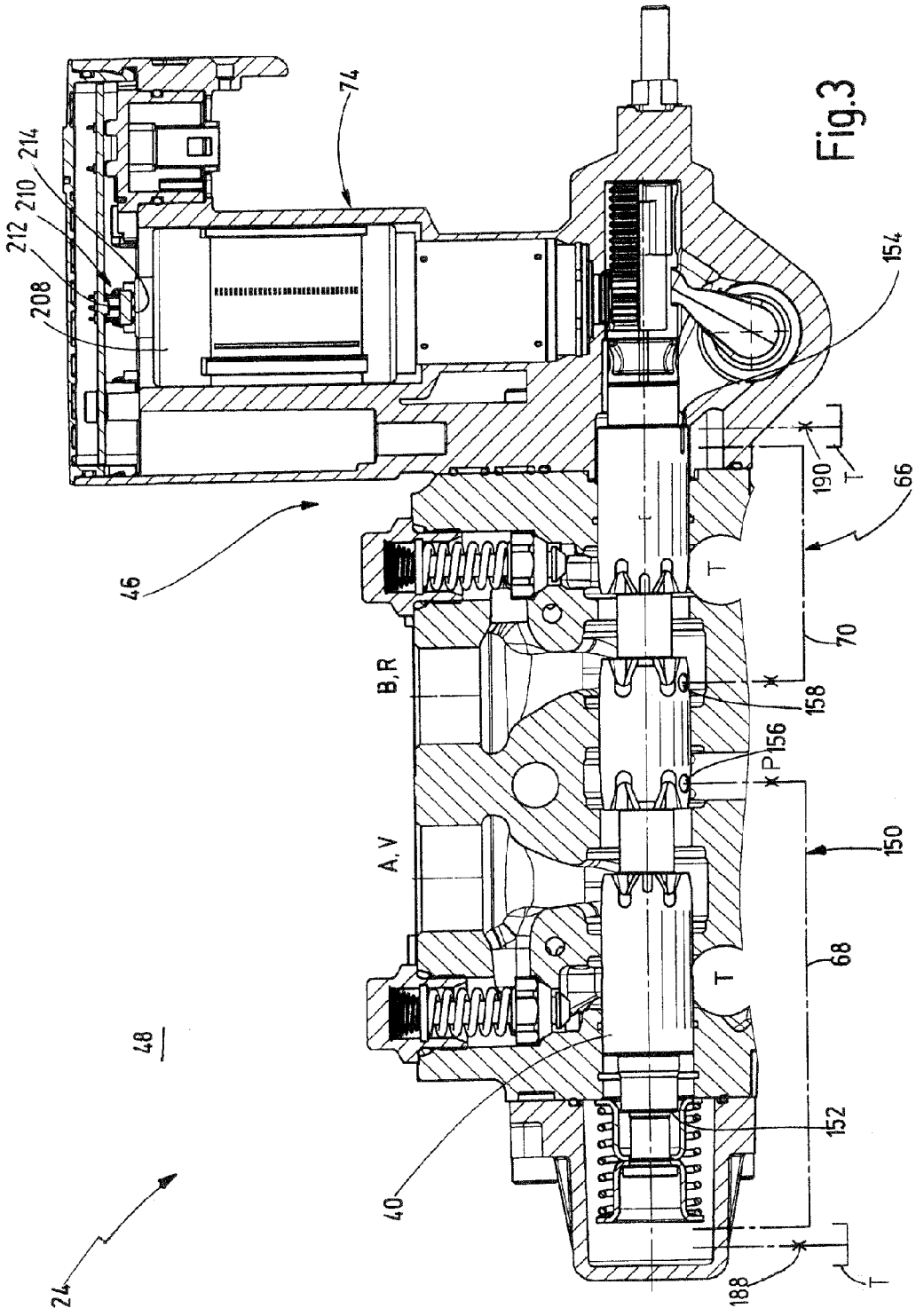
Fig.2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T
66
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A,V
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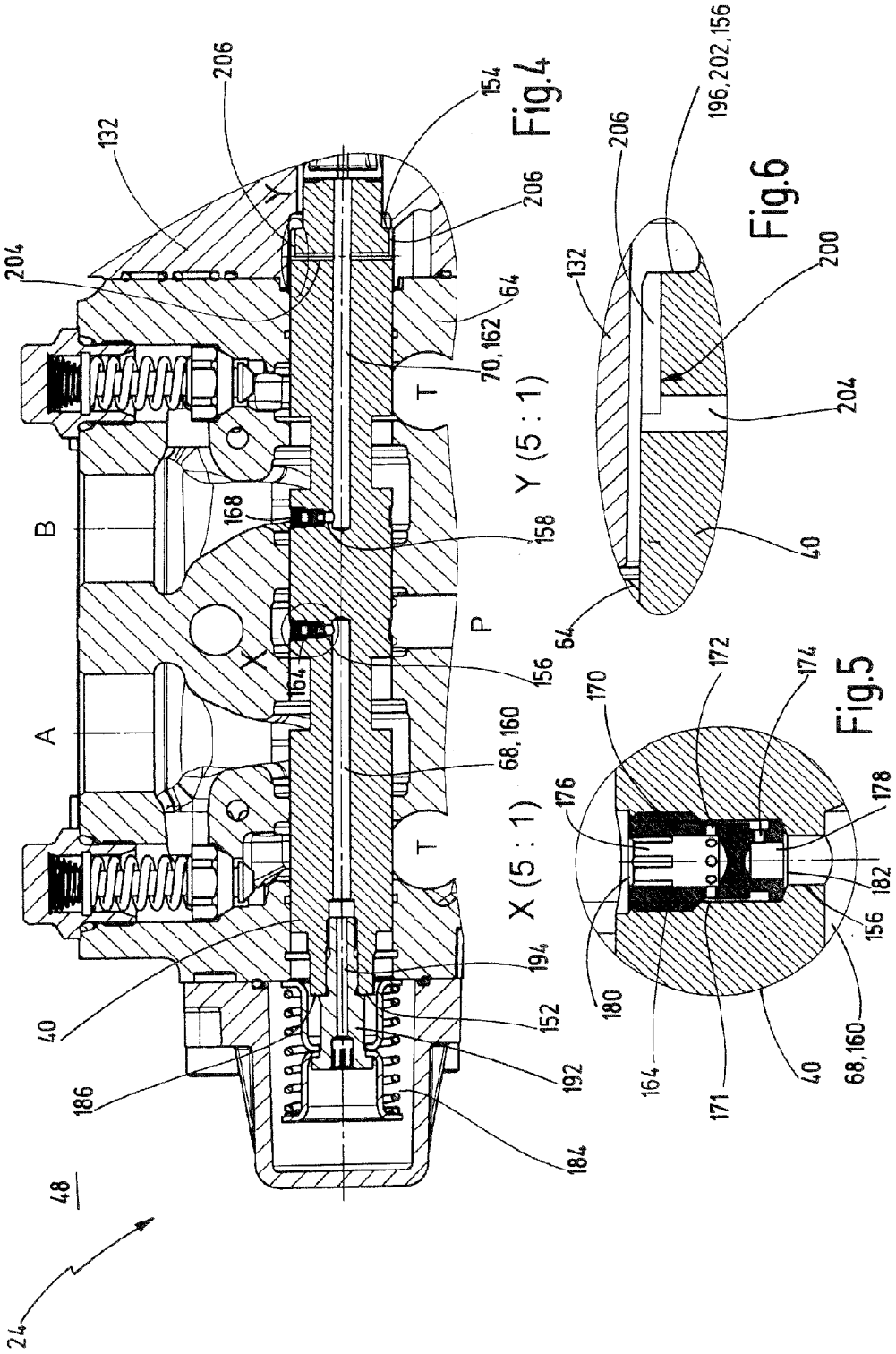
T

Fig.3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Y (5 : 1)
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154
206
132
204
206
Fig.4
64
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204
200
132
206
196, 202, 156
Fig.6
180
164
171
40
68, 160
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182
178
176
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174
Fig.5