

Feb. 7, 1967

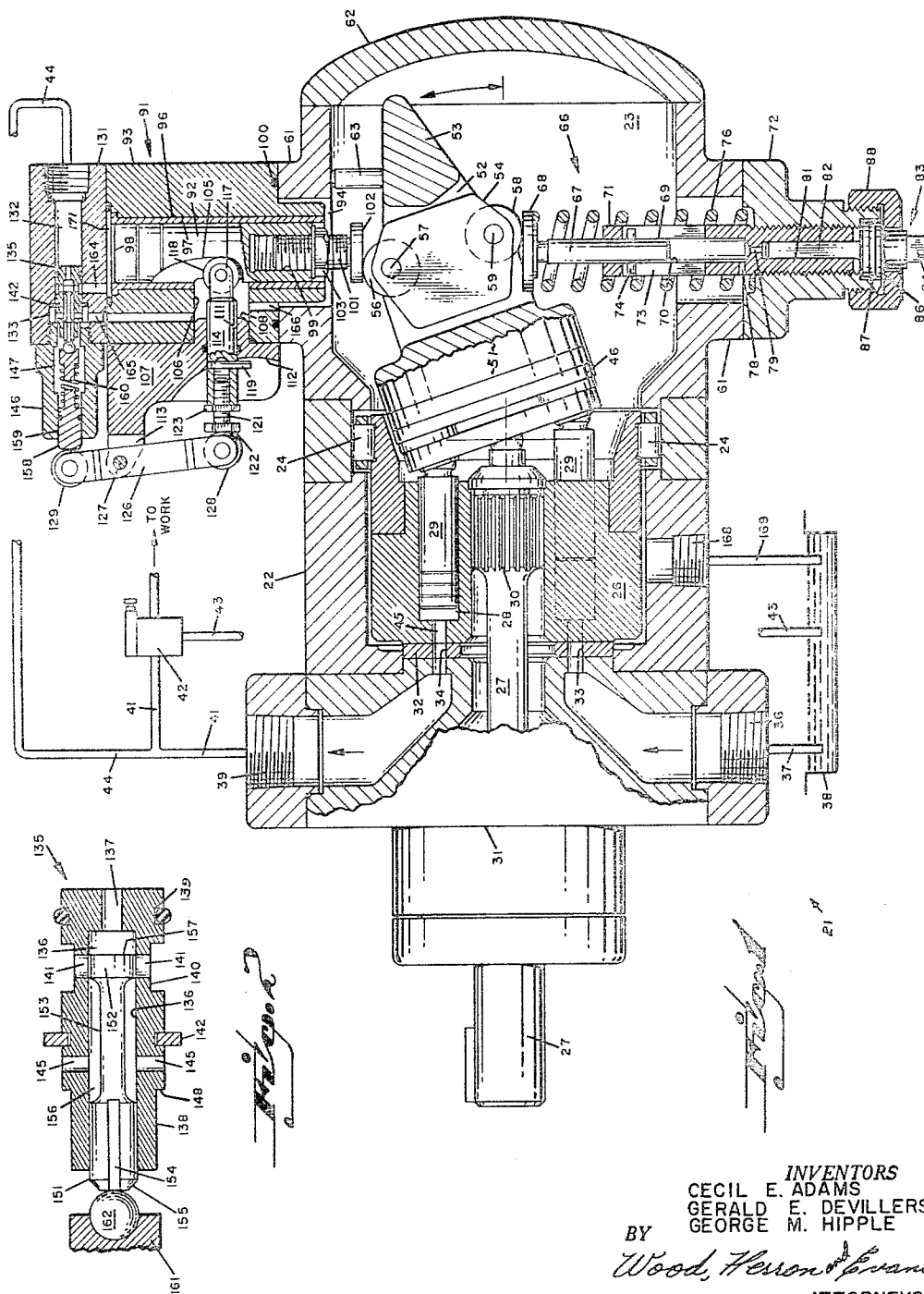
C. E. ADAMS ETAL

3,302,585

CONTROL FOR VARIABLE DISPLACEMENT PUMP OR MOTOR

Original Filed Sept. 24, 1962

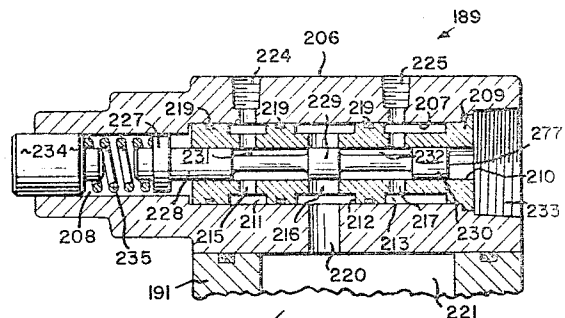
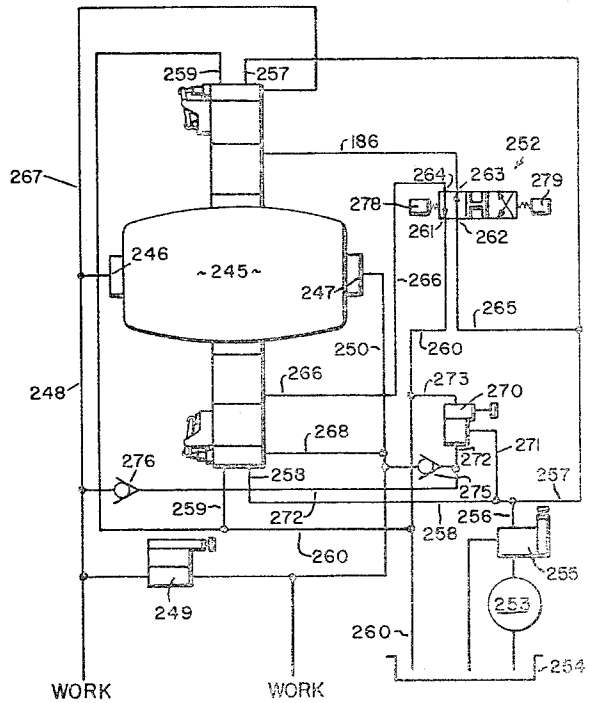
8 Sheets-Sheet 1



INVENTORS
CECIL E. ADAMS
GERALD E. DEVILLERS
GEORGE M. HIPPLE
BY
Wood, Henson & Evans
ATTORNEYS

3,302,585

8 Sheets-Sheet 2



BY GEORGE M. HIPPLE
Wood, Herron & Evans
ATTORNEYS

Feb. 7, 1967

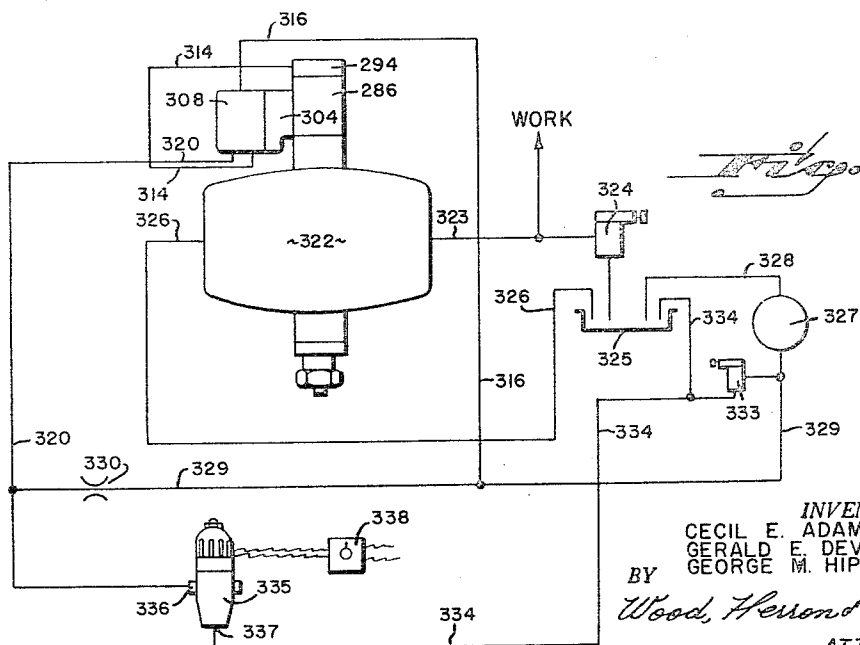
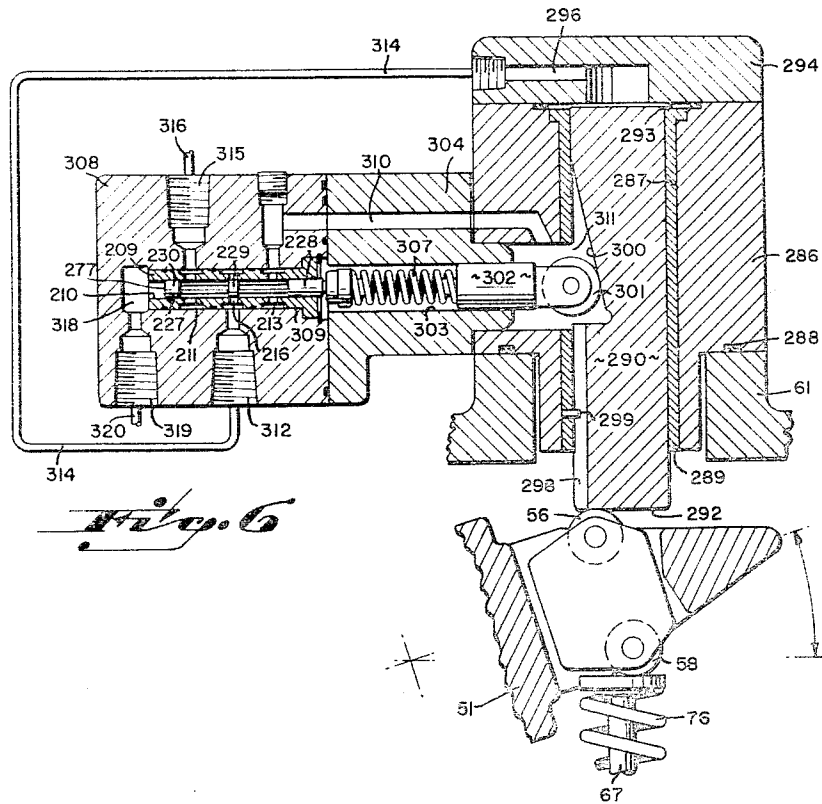
C. E. ADAMS ETAL

3,302,585

CONTROL FOR VARIABLE DISPLACEMENT PUMP OR MOTOR

Original Filed Sept. 24, 1962

8 Sheets-Sheet 3



INVENTORS
 CECIL E. ADAMS
 GERALD E. DEVILLERS
 GEORGE M. HIPPLE
 BY
Wood, Heron & Evans
 ATTORNEYS

Feb. 7, 1967

C. E. ADAMS ET AL

3,302,585

CONTROL FOR VARIABLE DISPLACEMENT PUMP OR MOTOR

Original Filed Sept. 24, 1962

8 Sheets-Sheet 4

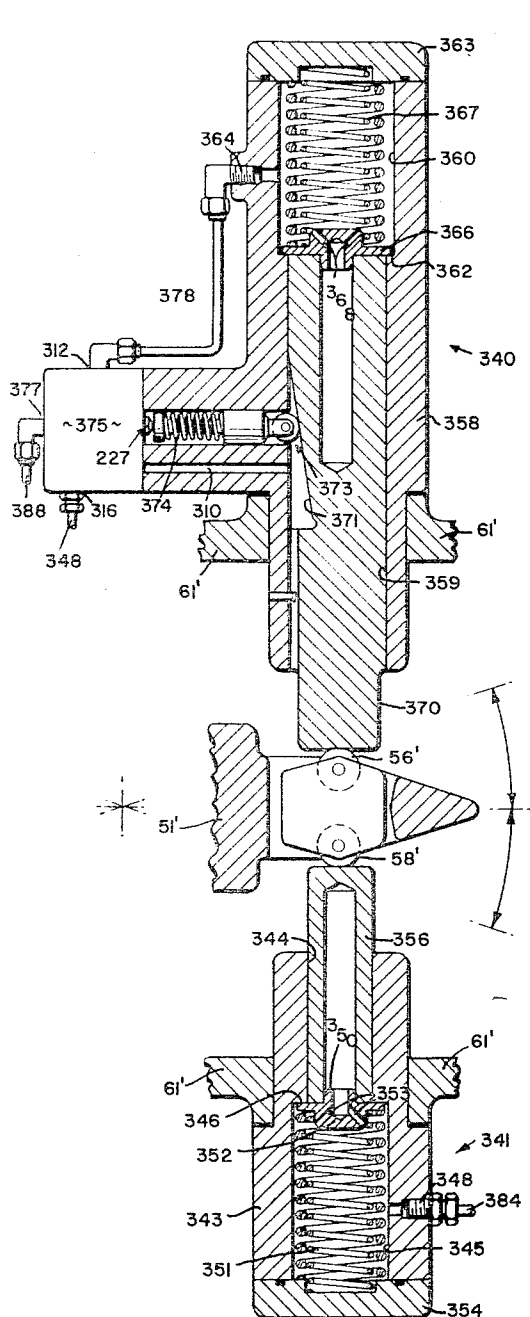


Fig. 8

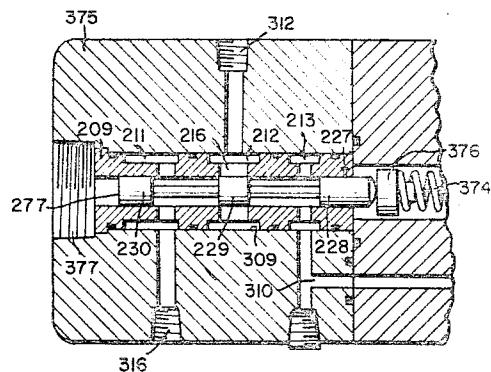


Fig. 9

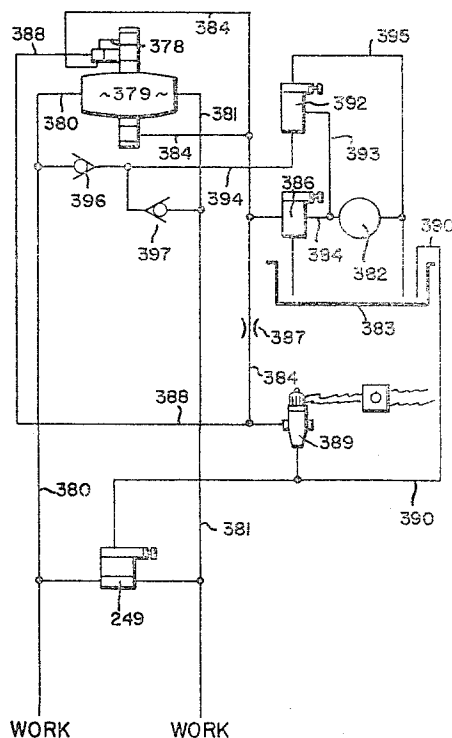


Fig. 10

INVENTORS
CECIL E. ADAMS
GERALD E. DEVILLERS
GEORGE M. HIPPLE
BY
Wood, Henson & Evans
ATTORNEYS

Feb. 7, 1967

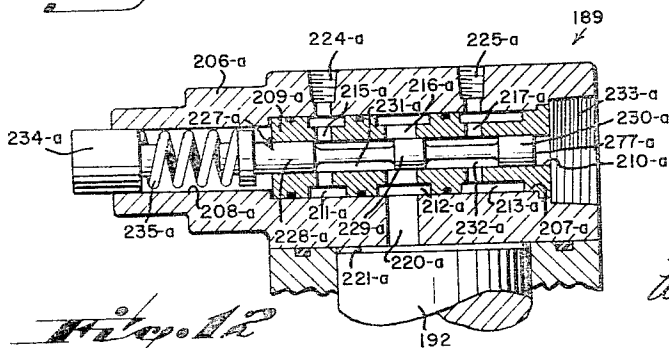
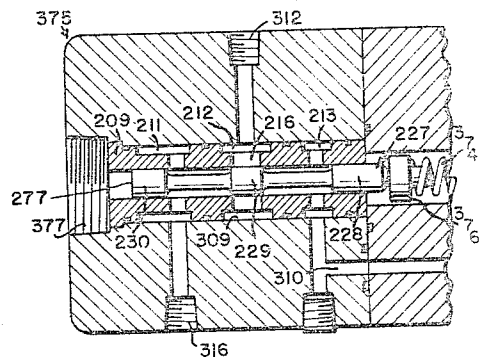
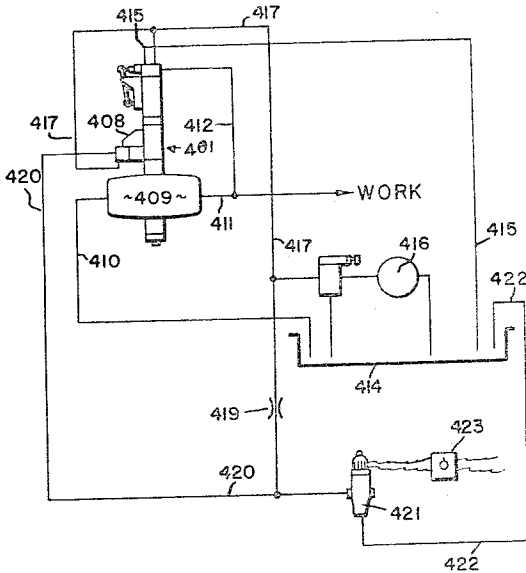
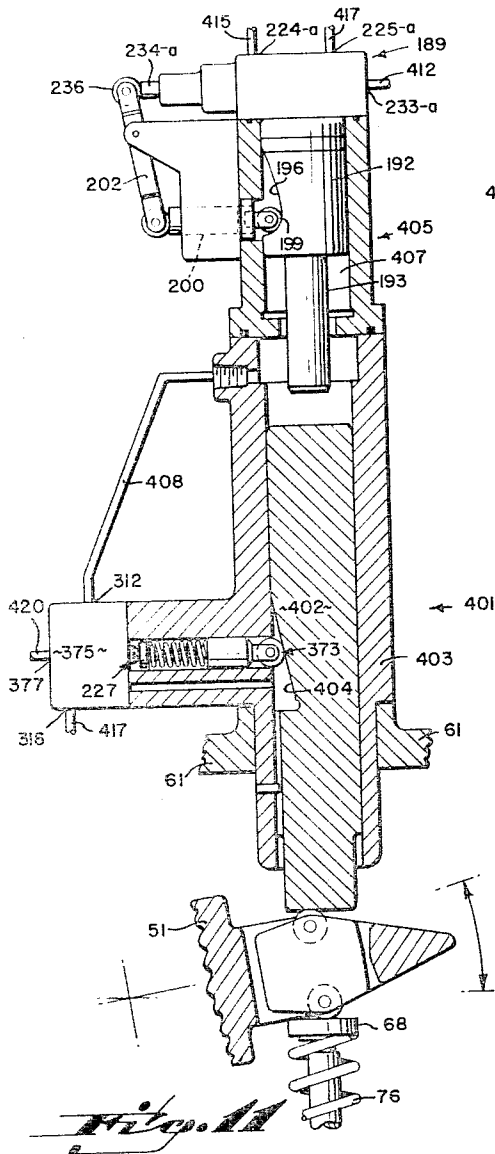
C. E. ADAMS ETAL

3,302,585

CONTROL FOR VARIABLE DISPLACEMENT PUMP OR MOTOR

Original Filed Sept. 24, 1962

8 Sheets-Sheet 5



INVENTORS
CECIL E. ADAMS
GERALD E. DEVILLERS
GEORGE M. HIPPLE
BY
Wood, Heron and Evans
ATTORNEYS

Feb. 7, 1967

C. E. ADAMS ET AL

3,302,585

CONTROL FOR VARIABLE DISPLACEMENT PUMP OR MOTOR

Original Filed Sept. 24, 1962

8 Sheets-Sheet 6

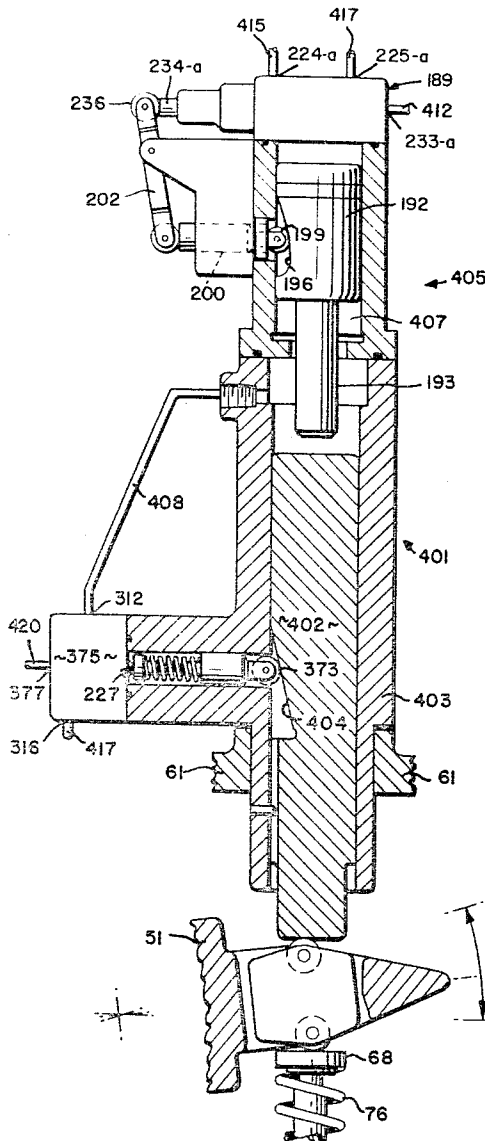


Fig. 15

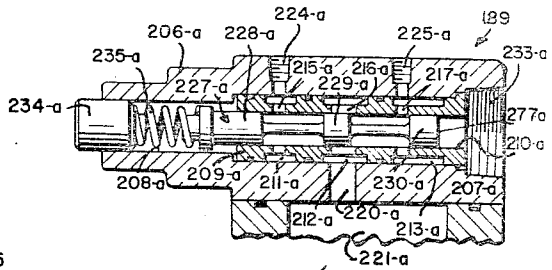


Fig. 16

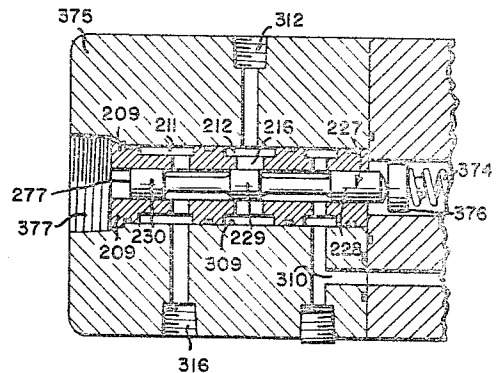


Fig. 17

INVENTORS
CECIL E. ADAMS
GERALD E. DEVILLERS
BY GEORGE M. HIPPLE
Wood, Heron & Evans
ATTORNEYS

Feb. 7, 1967

C. E. ADAMS ETAL

3,302,585

CONTROL FOR VARIABLE DISPLACEMENT PUMP OR MOTOR

Original Filed Sept. 24, 1962

8 Sheets-Sheet 7

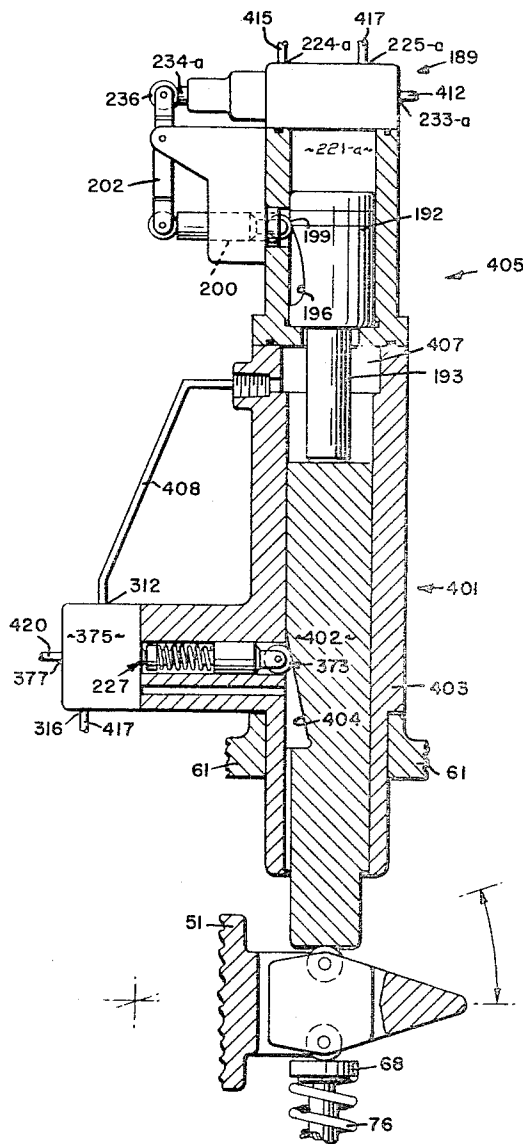


Fig. 18

INVENTORS
CECIL E. ADAMS
GERALD E. DEVILLERS
BY GEORGE M. HIPPLE
Wood, Heron & Evans
ATTORNEYS

Feb. 7, 1967

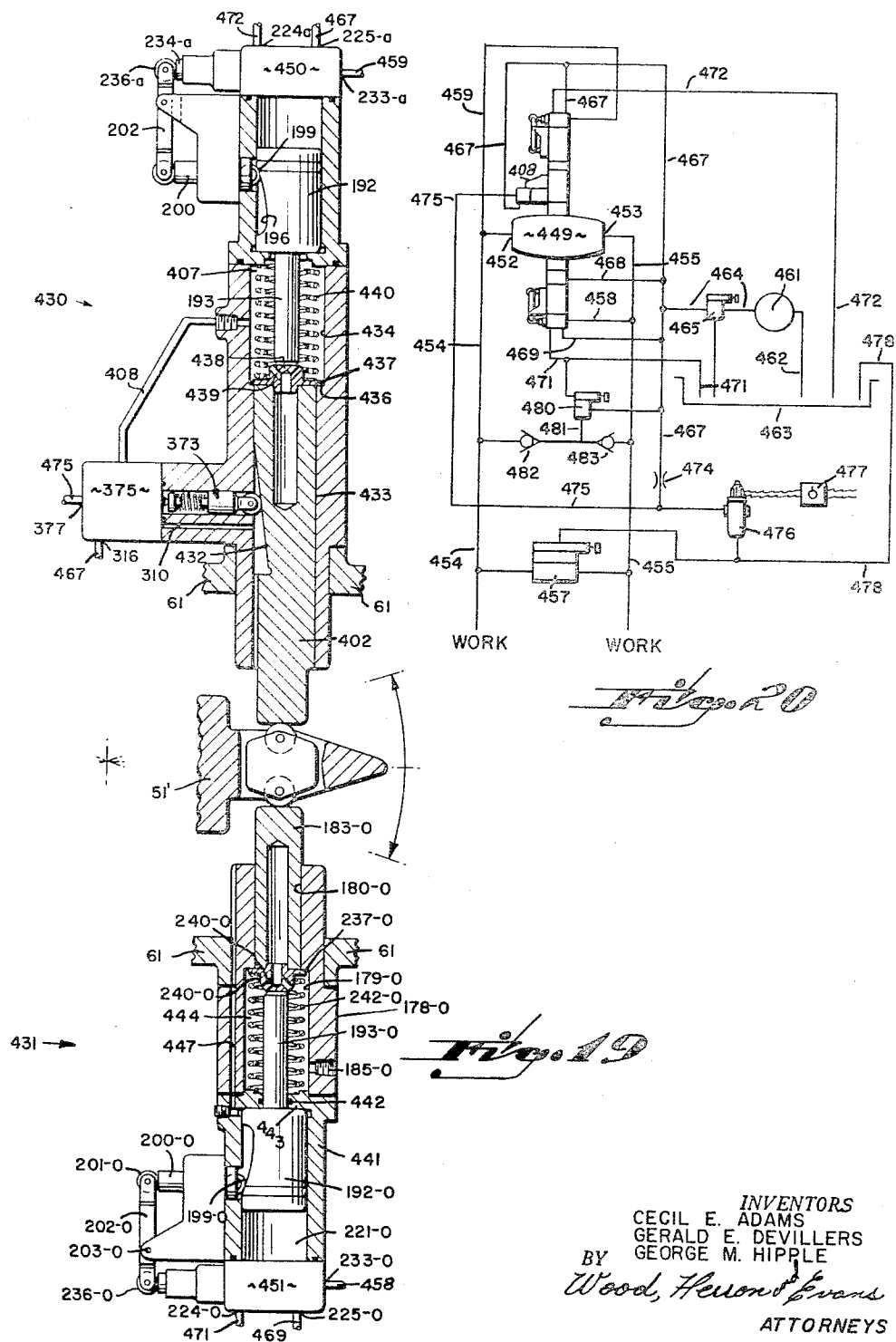
C. E. ADAMS ET AL

3,302,585

CONTROL FOR VARIABLE DISPLACEMENT PUMP OR MOTOR

Original Filed Sept. 24, 1962

8 Sheets-Sheet 8



INVENTORS
 CECIL E. ADAMS
 GERALD E. DEVILLERS
 GEORGE M. HIPPLE
 BY
Wood, Hewitt & Evans
 ATTORNEYS

1

3,302,585

CONTROL FOR VARIABLE DISPLACEMENT PUMP OR MOTOR

Cecil E. Adams, Gerald E. De Villers, and George M. Hipple, all of Columbus, Ohio, assignors to Abex Corporation, a corporation of Delaware
Original application Sept. 24, 1962, Ser. No. 225,484.
Divided and this application Jan. 17, 1966, Ser. No. 534,559

7 Claims. (Cl. 103—162)

This application is a division of our copending application Serial No. 225,484, filed September 24, 1962, now abandoned.

This invention relates to control devices for regulating the displacement of variable displacement fluid pressure translating devices. More specifically, in one aspect the invention relates to means for controlling the per revolution displacement of a hydraulic pump or motor in such manner that the torque of the translating device is limited from exceeding a predetermined value and is maintained substantially constant after the preselected value has been reached. In another aspect the invention relates to control devices whereby the displacement of a hydraulic pump or motor may be remotely controlled or changed to any desired value.

For purposes of describing this invention, variable volume, or more exactly, variable displacement fluid pressure translating devices may be defined as rotary pumps and motors which include means whereby the displacement of fluid per revolution of the device may be changed in magnitude. The devices may be of the piston type, the vane type, or of other types. As an illustration of a typical variable displacement device, a variable displacement piston pump includes means called a hanger for varying the stroke of the pistons whereby the volume of fluid displaced by the pistons during rotation of the barrel in which they reciprocate can be changed to provide different output volumes in unit time at a given rate of rotation of the barrel. The displacement changing means of such devices characteristically includes a movable member the position of which determines the displacement of fluid, for example by changing the angulation of a swash plate supported by the hanger, or by changing the off-center positioning of a cam ring.

Variable displacement devices may be classed as either single side type or cross-center type. In single side variable displacement translating devices, the displacement may be adjusted between zero and a maximum; in cross-center devices, the displacement may be adjusted from a maximum of flow, in one direction, to zero, to a maximum of flow in the opposite direction. The reference to "center" in the designation of these two general classes of translating devices is because the change in displacement is effected in the former instance by moving the displacement changing means through a range of positions on one side of the axis or center of the device, and in the latter instance by moving the displacement changing means from one side of center across the center line to the opposite side.

As previously suggested, apparatus in accordance with this invention may be used to control the displacement changing mechanism of a variable displacement fluid pressure translating device to limit or regulate the torque consumed by the fluid translating device from exceeding a preset value, and to maintain torque at the selected value when that value has been reached. As applied to a pump, the apparatus of this invention regulates the input torque consumed by the pump at variable or fixed speed. Moreover, inasmuch as pump horsepower is proportional to the product of pump displacement and pressure when the pump is operated at constant speed, the control of this invention thus limits or regulates at a pre-

2

selected value the horsepower of a variable displacement pump which is operated at constant speed. As applied to a variable displacement rotary fluid pressure translating device which is being operated as a fluid motor, the apparatus of this invention regulates the output torque of the motor at a constant value.

Torque limiters are often utilized to prevent the horsepower delivered to the translating device from exceeding the rated horsepower of the prime mover. For example, if a pump is driven by a ten horsepower electric motor, the horsepower which is supplied to the pump by the motor should be controlled so that the motor is not operated above its rated capacity. Thus, a pump which at its operating speed normally delivers a certain volume of fluid at say 2000 p.s.i. may suddenly be called upon to deliver a higher pressure, and by reason of the previously referred to functional interrelation between pressure, displacement and horsepower at constant speed, operation of the pump to deliver this higher pressure at the same displacement and speed may cause the prime mover to exceed its power rating. A torque limiter will reduce pump displacement to a lesser quantity such that the product of pressure and displacement will always be maintained at a substantially constant value corresponding to a pre-established torque and also to a pre-established horsepower, whereby the motor will not be overloaded.

In the torque limiter of this invention, the position of the displacement changing means of the translating device is automatically regulated in accordance with and in relation to system pressure, that is, the pressure supplied by the translating device if it is operating as a pump, or the pressure supplied to it if it is operating as a motor. If pressure tends to increase, then the displacement changing means is actuated by the torque limiter to reduce the displacement by an amount inversely proportional to the relative increase in the pressure, so that torque will remain constant.

Such control is effected by a fluid motor for moving the displacement changing means of the translating device. The operation of this motor is controlled by a valve to which an elastic valve operating force is supplied. The magnitude of this force is determined by means responsive to the position of the displacement changing means, and this force is opposed by system pressure.

In a preferred torque limiter embodying these principles a pressure operated piston moved the displacement changing means of the translating device, and this piston includes a cam surface the shape of which reflects the interrelationship between the pressure, displacement and torque. A cam follower riding on this cam surface is coupled through a spring to a servo spool or valve means which admits or releases pressure acting on the piston, and the force of this spring is opposed by a fluid force at system pressure. An incipient increase in system pressure overcomes the spring force applied by the cam follower to the servo spool, and actuates the servo spool to admit fluid to the piston cylinder to cause the piston to operate the displacement changing means of the pump to reduce displacement, so as to maintain torque constant. Conversely, reduction in the system pressure permits the spring force acting on the servo spool to overcome the fluid pressure acting on it, and the servo spool actuates the piston to increase displacement and thereby maintain torque at the preset value. The shape of the previously described cam surface determines the displacement which is established by the piston at any given pressure, to maintain the product of pressure and displacement substantially constant.

The remote displacement control or hanger positioner we have invented is similar to the torque limiter in that it also includes a fluid motor for positioning the displace-

ment changing means, the operation of which is controlled by a valve to which an elastic valve operating force is supplied. The magnitude of the elastic force is responsive to the position of the displacement changing means, but the elastic force is opposed by an independently adjustable control pressure. In a preferred form, the remote displacement control includes a piston which operates the displacement changing means of the translating device, which piston has a cam surface formed on it for regulating the force applied to a servo spool through a spring. The spring force acting on the servo spool in turn controls the application of pressure to the piston. The spring force applied to the servo spool is opposed by a control pressure signal. This control pressure signal is independent of system pressure, and thus independently controls displacement by operating the servo spool to admit or release pressure on the piston until the stress of the spring, as determined by a cam follower engaged with the piston cam surface and connected to the spring, balances the force of the control pressure signal applied to the servo spool. If the control pressure signal is reduced, the piston and the displacement changing means will be moved in one direction, and if the control pressure signal is increased, the piston and displacement changing means will be moved in the opposite direction, by an amount such that the mechanical force then applied through the spring to the servo spool will just balance the changed fluid force acting upon the servo spool.

In still another aspect of our invention we have provided a control for a variable displacement translating device whereby displacement may be set at any desired value so long as the torque being consumed by the device does not tend to exceed a preset maximum, combined with torque limiter means which override the displacement control when the torque tends to exceed the preset maximum and which then maintains torque at that maximum.

The invention can best be further described by reference to the drawings, in which:

FIG. 1 is a longitudinal cross-section through a variable displacement single side piston pump which has been equipped with a torque limiter including the features of one aspect of this invention.

FIG. 2 is an enlarged view of a portion of the hydraulic control mechanism of the torque limiter which is shown in FIG. 1.

FIG. 3 is a cross-section of mechanism including the features of another aspect of the invention, for controlling the torque of a cross-center type variable displacement pump or motor.

FIG. 4 is a cross-section through the hydraulic control cap of the torque limiter illustrated in FIG. 3.

FIG. 5 is a diagrammatic representation of a hydraulic system for operating a cross-center variable displacement translating device which is equipped with torque limiter mechanism of the type illustrated in FIG. 3.

FIG. 6 is a cross-section of hydraulic apparatus including the features of another aspect of the invention, for positioning the displacement changing means or hanger of a single side variable displacement pump or motor in accordance with a predetermined pressure signal.

FIG. 7 is a diagrammatic illustration of a hydraulic system for use with the positioner mechanism illustrated in FIG. 6, whereby the position of the displacement changing means of a variable displacement pump is controlled in accordance with an electrical signal.

FIG. 8 is a longitudinal cross-section of hanger positioning mechanism for use with a cross-center type variable displacement pump or motor.

FIG. 9 is a cross section of the hydraulic control apparatus of the hanger positioning mechanism illustrated in FIG. 8.

FIG. 10 is a diagrammatic illustration of a hydraulic system for use with the cross-center hanger positioner illustrated in FIGS. 8 and 9, whereby the displacement

changing means can be positioned on either side of center by means of an electrical signal supplied to a hydraulic control valve.

FIG. 11 is a longitudinal cross-section of apparatus including the features of another aspect of the invention, wherein a hanger positioner for controlling the displacement of a variable displacement single side pump or motor is combined with a hydraulic torque control for limiting the torque of the device, showing the apparatus when the positioner is controlling the hanger.

FIG. 12 is a cross-section of the hydraulic control cap of the torque limiter mechanism of the apparatus illustrated in FIG. 11.

FIG. 13 is a cross-section of the hydraulic positioner control mechanism of the apparatus illustrated in FIG. 11 showing the mechanism in the null or neutral attitude.

FIG. 14 is a diagrammatic illustration of a hydraulic system for operating the combined positioner and torque limiter illustrated in FIG. 11, whereby the hanger positioner is operated in accordance with an electrical signal.

FIG. 15 is a longitudinal cross-section similar to FIG. 11, but shows the apparatus when the torque limiter is assuming control of the hanger.

FIG. 16 is a view similar to FIG. 12 but shows the position of the servo spool in the hydraulic control cap of the torque limiter mechanism when the torque limiter has overridden the positioner and is reducing displacement.

FIG. 17 is a cross-section similar to FIG. 13, but shows the attitude of the hydraulic positioner control mechanism when the torque limiter is overriding it.

FIG. 18 is a longitudinal cross-section similar to FIGS. 11 and 15, but shows the apparatus when the torque limiter piston is in positive drive relation with the hanger positioner piston.

FIG. 19 is a longitudinal cross section of a hanger positioner for a variable displacement cross center fluid translating device, wherein the hanger positioner is combined with means for limiting the torque of the device when the displacement changing means is on either side of center.

FIG. 20 is a diagrammatic illustration of a hydraulic system for operating the apparatus shown in FIG. 19

Torque limiter—Single side type

As previously indicated in one aspect this invention relates to mechanism for varying the displacement of a fluid pressure translating device such as a pump in such a manner that the product of pressure and displacement per revolution is maintained constant after a preselected value has been reached. Such mechanism, when used with a pump operated at variable or fixed speed, will maintain the input torque requirement constant after it has reached a preselected level. Further, if the pump is operated at a fixed speed only, the input horsepower will additionally be maintained constant at the level previously selected for that speed.

One embodiment of a torque limiter which includes the features of this aspect of the invention is illustrated in FIGS. 1 and 2 of the drawings. For purposes of explanation, the torque limiter is shown in association with a generally conventional variable displacement single side piston-type fluid pump. It should be noted that the torque limiter of this invention is susceptible of use with different types of variable displacement devices, including both pump and motors, which need not necessarily be of the piston type, but which may be of the vane or other types wherein displacement is determined by and varies continuously with the position of the displacement changing mechanism of the device.

Insofar as relevant to a description of the torque limiter we have invented, the pump illustrated in FIG. 1 may be of the type which is fully disclosed and illustrated in E. H. Born et al., U.S. Patent No. 2,696,189, issued December 7, 1954, and entitled "Volume Indi-

cator for Hydraulic Pumps," or in L. E. Bonnette et al., U.S. Patent No. 2,699,123, issued January 11, 1955, and entitled "Hydraulic Pump or Motor." Reference is hereby made to those patents for a more complete description of the conventional elements of the pump illustrated in FIG. 1. Briefly, however, this pump or motor, which is designated generally as 21, and which for convenience is referred to hereinafter as a pump, includes a body 22 in which is defined an internal chamber 23. In this chamber 23 there is provided a circular bearing 24 for rotatably receiving a cylinder barrel 26. This cylinder barrel 26 is rotated in bearing 24 by a drive shaft 27 which is splined to it at 30. The cylinder barrel 26 is provided with circularly arranged parallel bores or cylinders 28 in which pistons 29 are slidable.

Between the left end of the cylinder barrel 26 and the head 31 of the body 22 there is provided a valve plate 32 having a fluid inlet opening 33 and a fluid outlet opening 34. The inlet opening 33 communicates with the suction or inlet port of the pump 21 which is formed in head 31 and which is designated as 36. In a typical arrangement, the inlet port 36 of the pump is connected by a line 37 to a fluid reservoir or tank which is shown diagrammatically in FIG. 1 and which is designated as 38. The outlet opening 34 in valve plate 32 communicates with the pump outlet or pressure port 39 which is formed in the pump head 31. A fluid conduit or line 41 is connected to pressure port 39, and this line 41 is typically connected through a conventional relief valve 42 to hydraulic equipment or machinery, not illustrated, upon which fluid delivered under pressure to line 41 is to perform work. The relief valve 42 has a drain line 43 which returns excess fluid to tank 38. A line 44 is also connected to line 41 and pressure port 39. The purpose of this line 44 will be explained hereinafter.

The cylinders 28 in barrel 26 communicate with cylinder ports 45 and these ports 45 in turn communicate, as the barrel 26 rotates, alternately with inlet opening 33 in valve plate 32 and outlet opening 34 in the valve plate. The pistons 29, which are reciprocable in cylinders 28, have shoes universally secured to their respective right ends which bear upon a cam or swash plate 46. The swash plate 46 is mounted to volume changing means comprising a hanger and yoke 51 which is journaled in trunnions (not shown) so as to be swingable about an axis normal to the plane of the drawings, whereby the angulation of the swash plate 46 with respect to the axis of drive shaft 27 may be varied.

As will be understood by those skilled in the art, as the drive shaft 27 is rotated, for example by prime mover not shown, the angulation of swash plate 46 causes the pistons 29 to reciprocate in their cylinders 28 as the barrel rotates, so as to effect pumping action. Fluid is drawn in from the reservoir 38 through line 37, and flows into the cylinders 28 through the opening 33 in valve plate 32. When the barrel 26 rotates, the fluid is displaced by the pistons and is forced out through opening 34, as the pistons are moved axially to the left by the shoes which bear upon the swash plate 46.

The hanger 51 has a central opening which is designated 52 and a rear cross arm or brace 53. A mounting member 54 is secured in the central opening 52 of the hanger, and this member 54 mounts an upper wheel 56 on a transverse shaft 57 and a lower wheel 58 on a transverse shaft 59. Wheel 56 projects above the upper face of the hanger 51, and wheel 58 projects below the lower face of the hanger.

The hanger 51 is enclosed within a housing 61 secured to body 22 which is closed at its right end by a cap 62. The hanger 51 can be moved in this chamber 23 to change the angulation of the swash plate 46 and thereby change the volume of fluid displaced by piston 29 each revolution of barrel 26.

When the hanger 51 is in center or "null" position, that is, when its center line is parallel to the axis of shaft

27, it will be apparent that the swash plate 46 is perpendicular to shaft 27, the pistons 29 are not reciprocated as the barrel 26 is rotated, and no significant volume of fluid is delivered by the pump. As the angulation of the swash plate 46 and hanger 51 is increased by moving hanger 51 away from null position, displacement also increases in response to the increasing reciprocating motion of the pistons 29 as the barrel 26 is rotated.

The maximum displacement of fluid is determined by a stop 63 affixed to the hanger cross arm 53, which stop abuts the interior of housing 61 to prevent further movement of the hanger 51 in the displacement increase direction. The pump 21 is a single side pump, that is, the hanger 51 can be moved only to one side of center and not to the other.

The hanger 51 is urged upwardly, that is, in the displacement increase direction, by means comprising a spring loaded plunger which is designated generally by 66 and which bears against the lower wheel 58 on the hanger. This plunger mechanism 66 includes a vertically movable piston 67 having an enlarged head 68 on which the wheel 58 rides as the hanger 51 is swung from position to position on its trunnions. The smaller diameter shank portion 69 of piston 67 is slidable in a bore 70 formed in a guide member 71. At its lower end this guide member 71 is threaded into a cap piece 72 which is secured to the side of housing 61.

Guide member 71 is provided with a longitudinally extending cross slot 73 intersecting bore 70 therein, and the plunger piston 67 has a transverse pin 74 which rides in this slot 73 as piston 67 moves in bore 70 within member 71. Pin 74 thereby prevents piston 67 from rotating about its axis. A spring 76 around guide member 71 urges piston 67 upwardly, into engagement with wheel 58, urging hanger 51 in the displacement increase direction. Movement of hanger 51 in the opposite direction, that is, toward null position, is limited by the point which the head 68 of piston 67 abuts the top of guide member 71, and in the single side pump which is illustrated in FIG. 1, this occurs when the hanger is in null position, so that the hanger cannot move to the other side of center.

So that hydraulic fluid within the bore 70 in guide member 71 will not be trapped therein as piston 67 moves downwardly, bore 70 is provided with a drain bore 78 extending transversely at its inner end. Bore 70 also communicates axially with a small diameter bore 79 which in turn communicates with a larger axial bore 81 also formed in guide member 71. Bore 81 is non-cylindrical or square in section, and slidably receives the squared shank portion 82 of an adjusting member 83. This adjusting member 83 preferably has a squared outer head 84, which projects externally of the pump, and has an enlarged cylindrical shoulder portion 86. The shoulder 86 fits in a cooperating bore or recess in cap piece 72, and has a groove 87 in which an O-ring is fitted to form a circumferential fluid seal with the cap piece 72. A locking nut or collar 88 is threaded to cap 72 over shoulder 86, and has a central opening through which the head 84 of the adjusting member 83 projects. In tightened position, the inner face of locking nut 88 bears against shoulder 86, clamping it against cap 72 and preventing adjusting member 83 from rotating.

By means of the above-described adjusting mechanism the position at which piston head 68 abuts the top of guide member 71 can be adjusted so that the hanger will at that point be at null or another desired position. This adjustment is effected by loosening the locking nut 88, turning the head 84 of adjusting member 83, whereby the square shank 82 of the adjusting member imparts rotation to guide member 71, which is threaded into cap 72. As guide member 71 is turned, it moves axially relative to shank 82, which is fixed in position, thereby changing the position of guide member 71 relative to the center line of the pump, and changing the lower limit of hanger movement and the minimum displacement of pistons 29.

As has just been described, the mechanism on one side (i.e., the lower side) of the pump 21 illustrated in FIG. 1 supplies a yieldable force tending to move the hanger 51 in the displacement increase direction. Controlled force for positioning the hanger in opposition to this force is supplied by a hydraulic control mechanism which is designated generally by 91 and which is located on the opposite side of the pump, in diametrically opposed position to the first described spring mechanism.

Generally speaking, the hydraulic control mechanism 91 includes a displacement control piston or torque limiter piston 92 which is axially aligned with the plunger piston 67 on the opposite side of the pump. The piston 92 is hydraulically actuated to move the displacement changing means of the pump 21, that is, to adjust or vary the angular position of the hanger 51, in response to and in inverse relation to the pressure being delivered by pump 21 at port 39 so that the pump torque will be limited to some maximum value. More specifically, as the pressure being supplied by the pump 21 tends or starts to increase, at the maximum displacement determined by stop 63, the product of pressure and displacement also increases, and therefore the pump consumes greater torque from the prime mover. When the preset torque limit is reached, the piston 92 is automatically moved downwardly, by means to be described, so that the hanger 51 is moved in the displacement decrease direction, thereby reducing the volume of fluid being delivered by the pump and simultaneously and proportionately reducing both input torque and horsepower, assuming the pump is being operated at a constant speed. Piston 92 responds oppositely to incipient decreases in input torque and permits upward movement of hanger 51 in the displacement increase direction.

In the hydraulic control mechanism 91, a body block 93 is secured to the side of housing 61 over an opening 94 in the housing, and the lower end of block 93 projects into the opening 94. This block 93 has a vertical bore 96, in which a cylindrical sleeve 97 is fitted. The block 93 is sealed to the housing 61 by means such as O-ring 100.

Piston 92 slides in sleeve 97 in alignment with plunger piston 67. Piston 92 has an upper face or surface 98, and is internally threaded at its lower end at 99. An externally threaded member 101 having a relatively large, flat head 102 is screwed into the threaded lower opening 99 in piston 92. This member 101 is secured with respect to piston 92 by means of a lock nut 103.

One side of control piston 92 is cut away to form a curved cam surface 105. The factors governing the shape of cam surface 105 will be described in greater detail hereinafter. A transverse or horizontally extending bore 106 is formed in body block 93, and this bore 106 extends through sleeve 97 into the bore therein in which the piston 92 slides, opposite cam surface 105 on the piston 92.

A generally L-shaped pivot member 107 is secured to the side of block 93, and this pivot member 107 has a cylindrical projection 108 on its inner face which fits into bore 106 in block 93. A horizontal bore 111 is formed in the pivot member 107, axially aligned with bore 106 in block 93 and opening thereinto. A saw cut 112 intersects bore 111 in pivot member 107 and an outwardly extending projection 113 above cut 112 in member 107 provides a pivotal mount for a lever or rocker arm, as will be explained.

A cam actuated plunger 114 is reciprocally received in bore 111 of member 107. This plunger 114 is provided at its inner end with a pair of spaced ears 117 between which a cam follower wheel 118 is rotatably secured. Wheel 118 rides upon the cam surface 105 in the side of piston 92. Cam operated plunger 114 is provided with a vertical pin 119 which rides in saw cut 112, thereby maintaining the axis about which cam wheel 118 rotates in horizontal position. At its outer end, plunger 114 is internally

threaded and receives an adjusting screw 121 which has a flat, enlarged outer end 122. Screw 121 is secured axially with respect to plunger 114 by a lock nut 123.

A rocker arm 126 is pivotable about a transverse shaft 127 presented by projection 113 of pivot member 107. This rocker arm 126 has a rotatable wheel 128 at its lower end and a rotatable wheel 129 at its upper end. Wheel 128 is engaged with and rides upon the head 122 of the adjusting screw 121 of cylinder 114.

It will be seen from FIG. 1 that if the control piston 92 is caused to move downwardly from the position in which it is shown, the angulation or the slope of the cam surface 105 will force cam follower wheel 118 and plunger 114 outwardly in bore 111, that is, to the left. As this occurs, rocker arm 126 will be swung clockwise about its shaft or pivot point 127, so that the wheel 129 at the upper end of the rocker arm will move to the right.

On the flat upper surface of block 93 there is secured a servo or control mechanism which is contained within a cap or block 131. This cap 131 has a horizontal through bore 132, the right end of which is connected to line 44, which in turn is connected to the outlet or pressure port 39 of the pump 21. A suitable threaded connection is provided for this purpose. Bore 132 in cap 131 is a stepped bore, and has an enlarged portion 133 adjacent its left end. A control sleeve 135, which is shown in enlarged view in FIG. 2, is sealingly fitted into bore 132.

Control sleeve 135 is of stepped cylindrical shape, and has a main axial bore 136 extending toward its right end and which communicates with a smaller axial bore 137. At its left end 138, sleeve 135 is of reduced diameter. A groove 140 extends circumferentially around sleeve 135, and transverse or radial ports 141 communicate between groove 140 and the bore 136 within the sleeve 135. An O-ring seal is mounted in a groove 139 adjacent the right end of the sleeve 135. A spring clip 142 is fitted around sleeve 135 to the left of groove 140, and this clip 142 abuts the shoulder in bore 132 of cap 131 (see FIG. 1) defined where the enlarged bore portion 133 meets the smaller diameter portion 132. A transverse or radial bore 145 in sleeve 135 which connects sleeve bore 136 with the enlarged bore portion 133 in cap 131.

A generally cylindrical guide 146 is threaded partway into the enlarged bore portion 133, and has an internal chamber 147. The inner end of guide 146 abuts the external shoulder 148 on sleeve 135 (see FIG. 2), holding clip 142 of sleeve 135 against the shoulder in cap bore 132.

As is best seen in FIG. 2 a shiftable valve member or a servo spool 151 is slidably received in bore 136 of sleeve 135. A land 152 having an axial dimension equal to the width of ports 141 is defined at the right end of the spool 151 by a circumferential groove 153. A longitudinal cut or groove 154 is formed in the left end portion 155 of spool 151. The ports 145 of sleeve 135 communicate with the space 156 surrounding groove 153 of spool 151.

A piston 158 is sealingly and slidably fitted into a bore 159 in guide 146, in alignment with spool 151. Wheel 129 of rocker arm 126 is engaged with and rides upon the outer face of this piston 158. A spring 160 surrounds the right end of this piston 158, and this spring at its other end bears on a ball centering member 161, which is movable in chamber 147 of the guide 146. This member 161 has a concave cavity in its right face, and a ball 162 is seated in this cavity and bears against the end of spool 151.

A pair of vertical bores intersect bores 132 and 133 in cap 131. One of these bores designated 164 communicates with groove 140 of sleeve 135, and at its lower end communicates with the interior of sleeve 97 in block 93. The second of these bores, bore 165, communicates with ports 145 in sleeve 135, and is extended downwardly through block 93 to transverse bore 106 therein. Another bore 166 communicates between bore 106 and the chamber 23 within housing 61 of the pump. This chamber 23 communicates with a tank outlet 168 in the

pump body 22, which outlet is connected to tank 38 by a line 169.

The operation of the single side variable displacement pump with the torque limiter attachment illustrated in FIGS. 1 and 2 may now be described. The pump receives fluid from tank 38 through line 37, and discharges it under pressure to line 41. For any given angular position of the hanger 51 and swash plate 46, the volume of fluid displaced to line 41 by the pistons 29 in a single revolution of barrel 26 is substantially constant. Therefore, at constant speed, for any given hanger position, and for any given pressure being delivered by the pump, the torque delivered to shaft 27 by the prime mover will be substantially constant. However, for any incipient change in the pump working load, the pressure in line 41 will change, and the torque consumed by the pump will tend to change proportionally. The hydraulic control mechanism 91 senses such pressure changes and rapidly responds to them in a manner whereby displacement is changed inversely to the pressure change, so that the product of the pressure and displacement will be maintained substantially constant.

For the purposes of explanation, let it first be assumed that the pump is operating with the hanger 51 in the position shown in FIG. 1, and that the pressure in line 41 begins to increase. Further assume that the pressure increase is not in excess of the pressure at which the relief valve 42 is set to operate, and therefore the relief valve 42 does not spill the excess fluid.

Under these circumstances, the pressure of fluid in line 44 reflects the pressure of fluid in line 41, the two lines being connected, and this pressure is applied by line 44 into bore 132 of cap 131 of the hydraulic control mechanism 91. This pressure is applied through small diameter bore 137 into bore 136 and acts on the right end surface 157 of control spool 151, urging that spool to the left against the action of spring 160. The force of spring 160 tends to hold spool 151 to the right, in opposition to the force of the hydraulic fluid acting on its right surface 157, and when this hydraulic force exceeds the force of the spring 160, spool 151 is moved to the left, thereby opening normally closed ports 141 to the fluid in bore 136. Fluid under pressure in bore 132 then flows through bore 137 and 136 through ports 141 to groove 140, and through bore 164 to the chamber 171 above the upper face 98 of the control piston 92. The pressure of this fluid is sufficient to overcome all movement-resisting forces acting on the hanger including the force of plunger mechanism 66, and the control piston 92 moves downwardly in sleeve 97, thereby moving the hanger 51 and swash plate 46 in the displacement decrease direction, so that the volume of fluid being delivered by the pump decreases.

As the control piston 92 moves downwardly, the cam wheel 118 rides on cam surface 105 of control piston 92. As can be seen in FIG. 1, when piston 92 moves downwardly from the position shown, the slope or curvature of the cam surface 105 will cause plunger 114 to be moved outwardly, to the left, in its bore 111 as wheel 118 follows the cam surface. As this occurs the wheel 128 of rocker arm 126, which bears upon screw 121, is swung outwardly, so that the wheel 129 at the other end of the rocker arm 126 moves to the right. This wheel 129 bears against the end of piston 158 which moves in bore 159 of guide member 146. As wheel 129 pushes piston 158 to the right, the compression of the spring 160 is increased, so that the spring force urging spool 151 to the right, in opposition to the fluid force acting on its right end surface 157, is increased. When this spring force equals the fluid force, and when land 152 just closes ports 141 in sleeve 135, as shown in FIG. 2, then the flow of fluid through bore 164 to chamber 171 above control piston 92 is stopped, and the control piston 92 remains fixed in that vertical position with respect to the hanger 51, and the per revolution volume of fluid delivered by the pump remains constant until another pressure variation occurs.

When the pressure of fluid in line 41 decreases, the fluid force acting on the right end face 157 of servo spool 151 is reduced in relation to the force of spring 160, and the spring moves the servo spool to the right, opening ports 141 to chamber 156 surrounding groove 153 of the spool 151. This establishes fluid communication between ports 145 and ports 141. Ports 145 communicate through bores 133, 165, 106 and 166 and opening 94 with the chamber 23 within housing 61, which chamber, as previously explained, is connected to tank 38 through line 169. Thus, fluid under pressure above control piston 92 is discharged to tank through bore 164, groove 140, ports 141, and through the chamber 156 to chamber 23. The force of spring 76 of the plunger mechanism 66 urges the hanger 51 in the displacement increase direction, and as the hanger moves in this direction it pushes piston 92 upwardly, inasmuch as the fluid force acting downwardly on piston 92 is released to tank as described. As the piston 92 is moved upwardly, cam wheel 118 is moved to the right, and follows the cam surface 105 in response to the force applied to it by spring 160. As the cylinder 114 moves to the right, the compression of spring 160 is decreased, so that the spring force urging servo spool 151 to the right is equally diminished. Fluid is discharged from chamber 171 above piston 92, and the piston 92 continues to move upwardly, until the spring force of servo spool 151 and the hydraulic force acting upon its right end 157 balance each other and land 152 closes ports 141. Under these circumstances, the fluid above the control piston 92 is trapped, the control piston 92 remains fixed in position, and the pump 21 continues to deliver a constant per revolution volume of fluid until the pressure again changes in one direction or the other.

Under stable operating conditions, the hydraulic control piston 92 establishes a displacement which maintains a pressure just sufficient to keep the land 152 in closing contact with the ports 141, so that fluid flows neither into nor out of the chamber 171 above control piston 92. As the pressure tends to change from the pressure required to hold the land 152 in this precise position, the land 152 will be moved in one direction or the other either by spring 160 or the fluid pressure, and will change the position of the control piston 92 and the hanger 51 so that the pump displacement will be oppositely changed to maintain the pump torque constant.

From the foregoing, it will be seen that pump displacement is controlled by piston 92, and that piston 92 in part controls the compression of spring 160, which spring force determines the fluid pressure in line 44 required to change the vertical position of the hanger 51. The shape of cam surface 105 determines the fluid pressure required to move servo spool 151 at any given hanger position. The shape of this cam surface 105 is determined mathematically and resembles a rectangular hyperbole to each horizontal plane passing through the cam surface 105 there corresponds a different displacement, and to each vertical plane passing through the cam surface there corresponds a different fluid pressure. The cam surface is so shaped that the product of the displacement corresponding to the vertical coordinate of any given point on the cam surface and the pressure corresponding to the horizontal coordinate of the same point, equals a constant which is proportional to the pump output horsepower, and therefore to its input horsepower.

The head 102 of stop 101 of the control piston 92 is vertically adjustable relative to the control piston, so that the vertical position of the cam surface 105 with respect to the hanger 51 can be changed. By means of this adjustment, the specific torque limit maintained by the limiter mechanism can be changed over a range of settings. Also screw 121 can be adjusted relative to cam surface 105 so that the pressure on spring 160 can be regulated for best operation with the individual pump in which the control mechanism 91 is installed, and to change the limit.

In actual tests, we have found that the torque delivered to a pump equipped with the limiter we have invented will be maintained constant within a close approximation of the preselected value. Moreover, the range of variation from that value does not change significantly with torque. Thus, in a pump operated at constant speed the shape of cam surface 105 might be designed specifically for, say, 40 horsepower, but the limiter can be adjusted to be almost equally effective between 20 and 50 horsepower.

FIGS. 1 and 2 illustrate the principles of the horsepower and/or torque limiter of the invention in relation to a single side pump. FIGS. 3, 4 and 5 illustrate related mechanism, in accordance with another aspect of the invention, whereby the torque delivered to a cross-center pump is regulated at a constant value.

Torque limiter—Cross center type

In the single side pump shown in FIG. 1, movement of the hanger 51 in the displacement decrease direction is limited by a stop so that the hanger cannot move past the central position, in which substantially no fluid is delivered by the pump and in which the plane of the swash plate 46 is perpendicular to shaft 27. In a so-called cross-center type pump, the motion of the hanger is not limited to one side of center, and the hanger can move from one side of center to the other. As this is done, the direction of rotation of shaft 27 remaining the same, the direction of fluid flow through the pump is reversed, as will be understood by those skilled in the art.

Cross-center pumps are well known and it is not necessary to describe them in detail herein to explain the principles of the cross-center horsepower limiter we have invented. In FIG. 3, the displacement changing means or hanger 51' of a cross-center pump is shown. Similar to the hanger 51 of the single side pump illustrated in FIG. 1, the hanger 51' is equipped with an upper wheel 56' and a lower wheel 58'. The hanger 51' is enclosed without a housing 61', only portions of which are shown. The other details of the cross-center pump may be conventional.

Diametrically aligned on opposite sides of housing 61' there are provided hydraulic hanger control or torque limiter mechanisms which are designated generally by 176 and 177. These mechanisms 176 and 177 are identical to each other, and control the hanger 51' on opposite sides of center. Since the two mechanisms 176 and 177 are identical, for purposes of description it will suffice to describe the upper mechanism 177.

In the mechanism 177, a hollow cylindrical body block 178 is secured and sealed to the housing 61', and projects through an opening therein into the chamber 23' in the interior of housing 61'. Interiorly, this block 178 has a large diameter upper bore 179 and a co-axial smaller diameter lower bore 180. A piston 183 is slidably and sealingly received in bore 180 of block 178, and this piston 183 has a lower end surface 184 which bears against the upper wheel 56' of the hanger 51'. A port 185 is formed through block 178 and communicates with bore 179 therein, and a fluid line 186 is connected to port 185.

To the top of body block 178 there is secured structure 188 which in several respects is similar to the hydraulic control mechanism 91 of the pump illustrated in FIG. 1. The primary difference between the structure 188 shown in FIG. 3 and the mechanism 91 of FIG. 1 resides in their respective control caps 189 and 131.

The structure 188 includes a cylindrical portion 191 which is hollow and which receives a control piston or torque limiter piston 192. An adjustable stop 193 is threaded into the bottom of control piston 192, and this stop 193 has a head 195 which projects into bore 179 of body block 178. The position of this head 195 may be adjusted by turning stop 193 relative to piston 192. Control piston 192 presents a cam surface 196 along one

side, which is similar to the cam surface 105 of the piston 92 shown in FIG. 1. A cam follower wheel 199 is engaged with cam surface 196, and this cam wheel 199 is connected to a horizontally sealingly slidable plunger 200.

A wheel 201 at one end of a rocker arm 202 rides upon the end of the cylinder 200, and swings the rocker arm 202 about a pivot point 203 in accordance with the motion of plunger 200.

The control cap structure 189 is illustrated in FIG. 4. The cap 189 includes a body 206 which has a horizontal through bore 207. Bore 207 opens at one end to a smaller bore 208. A sleeve 209 is secured axially within bore 207. This sleeve 209 has an axial opening or bore 210 and is externally provided with three axially spaced circumferential grooves 211, 212, and 213. Radial ports 215 communicate through the sleeve between groove 211 and axial bore 210 therein, ports 216 communicate between groove 212 and the bore 210, and ports 217 communicate between groove 213 and bore 210. O-ring seals 219 are provided on each side of grooves 211 and 212. A vertical bore 220 extends through the cap body 206 in communication between groove 212 of sleeve 209 and the chamber 221 in cylindrical portion 191 above piston 192. Ports 224 and 225 communicate through the cap body 206 with grooves 211 and 213 respectively.

A servo spool 227 is slidable and sealingly fitted in bore 210 of the sleeve 209. This servo spool 227 has three lands 228, 229, 230, the central land 229 having an axial dimension nominally equal to the axial dimension of ports 216. A groove 231 separates land 228 and land 229, and a groove 232 separates land 229 and 230. A threaded connection 233 is provided at the right end of bore 210.

A piston 234 is slidable and sealingly located in bore 208 of cap body 206, and a spring 235 is urged by this piston 234 against a shoulder formed on the left end of spool 227. Piston 234 is engaged by a wheel 236 at the upper end of rocker arm 202.

With reference to body block 178 of the upper horsepower limiter assembly 177, a shoulder 237 is defined between bores 179 and 180 therein. Above this shoulder 237, a circular washer 238 is movable in bore 179. Washer 238 has a raised center 239, and a pair of diagonally extending bores 240 to provide fluid communication through washer 238 between bore 179, and bore 180. A spring or springs 242 bears against an internal shoulder 243 at the lower face of cylinder portion 191 and urges washer 238 downwardly against the lower shoulder 237.

The assembly 176 on the opposite side of housing 61' is identical in all respects to the assembly 177, and for convenience elements of assembly 176 bear the same numbers as the corresponding elements of mechanism 177, followed by -O, denoting that the member is on the opposite sides of the pump. The control cap 189-O of the lower assembly 176 is also identical to the cap 189 shown in FIG. 4, and its components are similarly numbered with an accompanying -O.

FIG. 5 illustrates a hydraulic circuit or system including a cross-center fluid pump which is equipped with the torque control mechanism illustrated in FIGS. 3 and 4. In FIG. 5, the cross-center pump is designated as 245 and this pump 245 has a port 246 on one side and a port 247 on the opposite side. Depending upon the position of the hanger 51' of the pump 245, for a given direction of rotation of the pump drive shaft, one of the ports 246 and 247 will act as the inlet port and the other port will act as the pressure port. As the hanger 51' is moved across center, the direction of flow through the pump 245 will be reversed.

Port 246 of pump 245 is connected to a fluid line 248, which is connected to hydraulic apparatus, not shown, upon which work is to be performed, and which is also connected to one side of a dual acting or two-way relief valve 249. The dual relief valve 249 is suitably of the type

having two ports and valve structure between those ports which will open in response to excessive pressure at either port to permit excess fluid to flow to the other port. By way of illustration, a dual relief valve having these characteristics is disclosed in Adams patent application Serial No. 171,135, filed February 5, 1962, entitled "Dual Direction Relief or Sequence Type Valve," and reference is hereby made to that application for a description of a suitable dual relief valve 249.

The other port 247 of pump 245 is connected to a line 250 which is connected to hydraulic machinery upon which work is to be performed, not shown. Line 250 is also connected to the second port of the dual relief valve 249. In the operation of the pump 245, when port 246 comprises the pressure port, fluid under pressure is supplied to line 248 and through that line to the work connection; fluid under pressure in excess of the pressure at which relief valve 249 is set to open is spilled through the valve 249 to line 250 and returns to the inlet port 247 through line 250. When line 247 comprises the pressure port, fluid under pressure in excess of pressure at which relief valve 249 is set to operate is spilled through the valve 249 to line 248, and enters the pump port 246, which under those circumstances comprises the inlet port.

As will be explained more fully hereinafter, the torque limiter illustrated in FIG. 3 utilizes a separate source of fluid pressure for operation, in contrast to the limiter previously described. In the system of FIG. 5, this working fluid pressure is supplied by a small volume pilot pump 253, which receives fluid from a tank 254, and which supplies fluid under pressure through a relief valve 255 to a line 256. Excess fluid is spilled by relief valve 255 to tank 254.

Line 256 is connected to port 225 of the cap structure 189 of the upper control mechanism 177, by a line 257. Similarly, line 256 of pilot pump 253 is connected to the port 225-O of the lower mechanism 176 by a line 258. Port 224 of the upper control mechanism 177 is connected to port 224-O of the lower mechanism 176 and to the tank 254 by means of lines 259 and 260.

A solenoid operated, spring centered, four-way valve is illustrated diagrammatically and is designated as 252. The valve 252 has four ports, 261, 262, 263 and 264, and a spool movable between three positions. In center position of the spool, all four of the ports 261-264 are connected together. In the position in which the spool is diagrammatically illustrated in FIG. 5, port 262 is connected to port 263, and port 264 is connected to port 261. In the third position, port 262 is connected to port 264 and port 263 is connected to port 261. The position of the spool is controlled by solenoids 278 and 279 at its opposite ends. Such four-way valves are well known in the art and need not be described in greater detail.

Port 262 of the four-way valve 252 is connected by a line 265 to line 257. Port 263 of the valve 252 is connected to line 186, which is connected to port 185 of the upper mechanism 177. Port 264 is connected by a line 266 to port 185-O of the lower torque control mechanism 176. Port 261 is connected to tank line 260.

Port 246 of pump 245 is connected by line 267 to port 233 of the control cap 189 of the upper mechanism 177. Similarly, a line 268 connects the corresponding port 233-O to port 247 on the opposite side of the pump 245.

Makeup fluid is supplied to the main pump system from line 256 of pilot pump 253 through a pressure reducing valve 270 which is connected to line 256 by a line 271. The pressure reducing valve 270 may for example suitably be of the type which is described in C. E. Adams Patent No. 2,747,606, issued May 29, 1956, entitled "Pressure Reducing Valve," to which reference is made. Fluid passes through pressure reducing valve 270 to a line 272, wherein the valve 270 maintains a pressure slightly above, for example 50 p.s.i. above, atmospheric pressure. The pressure reducing valve 270 has a tank line 273 which is connected to line 260.

Line 272 from the pressure reducing valve is connected through a check valve 275 which permits fluid flow from the valve 270, to line 250. Line 272 is connected through a second check valve 276 to line 248, check valve 276 permitting flow from line 272 to line 248 but not in the reverse direction.

The four-way valve 252 may be actuated manually or automatically to swing the hanger 51' across the center of the pump 245. With the hanger 51' in the position shown in FIG. 3, it is assumed that the pump 245 is delivering fluid under pressure to port 247, and that the port 246 comprises the inlet line to the pump. Under these conditions, the four-way valve 252 is actuated so that the fluid connections through it are as shown in FIG. 5. Thus, fluid under pressure delivered by pilot pump 253 to line 256 is supplied through the four-way valve 252 from line 265 to line 186, through port 185 into bore 179 beneath control piston 192. Fluid under pressure in line 257 is also delivered to port 225 of the cap 189 of the upper assembly 177, and this fluid flows into groove 213 and through ports 217 into the chamber in bore 210 around groove 232 of the spool 227. Since port 246 is under these conditions the pump inlet port, the pressure in line 267 is low, and this low pressure is reflected at port 233 and in bore 210, to the right of land 230 of spool 227.

Under these conditions fluid under pressure is also supplied from line 256 and line 258 to port 225-O of the lower torque limiter assembly 176. Fluid at the pressure in line 250 is applied to the right end of land 230-O through line 268. The port 185-O of assembly 176 is connected to tank 254 through the four-way valve 252 by lines 266 and 260.

With reference to the control structure contained within the cap 189 of the upper mechanism 177, fluid acting on the right face 277 of spool 227 is at tank pressure, inasmuch as that fluid is at the pressure at the inlet side 246 of the pump 245; therefore, spring 235 urges control spool 227 to the right from the position shown in FIG. 4, so that port 216 is opened by land 229 and fluid above piston 192 in chamber 221 flows through bore 220, groove 212, ports 216, through the chamber around groove 231 and outwardly through ports 215, groove 211, and port 224 to line 259 which is connected to tank. No force then tends to hold the control piston 192 downwardly, and the pressure delivered by the pilot pump 253 to line 186, which is applied below the piston 192, lifts the piston 192 to its uppermost position. The same fluid pressure that is applied through port 185 is also applied through diagonal bores 240 into the chamber in bore 180 of cylinder 178, and urges piston 183 therein downwardly, thereby applying a force tending to urge the hanger 51' downwardly.

As previously explained, when port 247 is the outlet port of pump 245, 185-O of the lower control mechanism 176 is connected to tank 254.

The system pressure delivered by the pump 245 is applied through line 268 to the right end face 277-O of spool 227-O of the lower torque limiter control mechanism 176. This hydraulic force is opposed by the force of spring 235-O, the compression of which is controlled by the vertical position of the cam surface 196-O through the rocker arm-cam follower linkage. When, for example, pressure delivered by the pump 245 tends to increase, that pressure moves spool 227-O to the left, whereby ports 216-O are opened by land 229-O. Fluid under pressure at port 225-O, from line 258, will then flow through bore 220 into the chamber 221-O below piston 192-O. The fluid force from this pressure overcomes the lesser force caused by pressure in bore 180 on piston 183, which is of a smaller cross-sectional area than piston 192-O. As the piston 192-O moves upwardly in response to this imbalance of forces, stop 193-O pushes on washer 238-O, which in turn raises the piston 183-O, which moves the hanger 51' in the displacement

decrease direction. Upward movement of the piston 192-O continues until the force applied to spring 235-O exactly balances the fluid force acting on face 277-O of spool 227-O and land 229-O closes ports 216-O. The shape of the cam surface 196-O is so designed, as previously described, that this will occur at such a displacement that the product of that displacement and the pressure of the fluid then being delivered by the pump will be maintained at a substantially constant value. As with the single side torque limiter, the torque maintained by the cross center apparatus may be changed by the adjustable stops 193, 193-O, and by the plungers 200, 200-O, which may also be adjustable in length if desired. It should be noted that the cross center apparatus provides for limiting at different torques on opposite sides of center, if desired.

When with the hanger 51' in the lower position illustrated in FIG. 3, the fluid pressure being delivered by the pump tends to decrease, and the pump torque thereby also tends to decrease, the hydraulic force on face 277-O of the servo spool 227-O is reduced, and the spring 235-O moves the spool 227-O to the right thereby providing fluid communication between the chamber 221-O below the head of piston 192-O and tank 254, through port 224-O. As this occurs, the pressure acting on the opposite or upper face of piston 192-O, which pressure is supplied by the pilot pump 253 through port 185-O, moves the piston 192-O downwardly, thereby decreasing the compression of spring 235-O until the force of that spring just balances the hydraulic force on spool face 277-O and the land 229-O closes ports 216-O.

FIG. 4 illustrates the balanced or steady state condition of pressure wherein the ports 216 are closed and the pressure of fluid on face 277 is exactly balanced by the force of the spring 235. Under these conditions fluid flows neither into nor out of the chamber 221 and the piston 192 is stationary.

As previously explained, the direction of fluid flow through pump 245 can be reversed by moving hanger 51' across center, that is, from the position shown in FIG. 3 to a position on the other side of the center line. In the hydraulic circuit illustrated in FIG. 5, this may be done by actuating the four-way valve 252 so that the connections to lines 186 and 266 are reversed. With reference to the solenoid operated valve which is illustrated in FIG. 5, valve 252 is shown with solenoid 278 on its left end energized and the solenoid 279 on its right end unenergized. By energizing solenoid 279 and de-energizing solenoid 278, pressure at port 262 is applied to port 264 and is applied through line 266 to port 185-O of the lower assembly 176, and line 186 is connected to tank port 261. Actuation of the solenoids 278 and 279, or any equivalent valve actuating mechanism, may be done either manually or automatically in accordance with some programmed sequence.

When the torque limiter is in the position illustrated in FIG. 3 and the four-way valve 252 is operated so that the connections to its ports 263 and 264 are reversed from those shown, port 185-O of the lower assembly 176 is connected to the pilot pump 253 and the fluid pressure acting downwardly on piston 183 is released. Piston 183 then will move upwardly in response to pressure applied to the opposite piston 183-O through port 185-O. The hanger 51' will thereby be moved upwardly or counterclockwise, across the center line of pump 245. As this occurs, the direction of flow through the pump is reversed and fluid under pressure is delivered to port 246 of pump 245.

As can be seen in FIG. 5 this pressure is applied through line 267 to port 233 of the upper control cap 189 and opposes the force of spring 235. Simultaneously, the pressure previously acting on the end face 277-O of spool 227-O of the lower mechanism 176 drops to about tank pressure, and spring 235-O moves spool 227-O to the right, thereby providing fluid communication between chamber 221-O below control piston 192-O and tank

through port 224-O. The lower control piston 192-O is thereby moved downwardly in its bore by the unbalanced fluid pressure acting upon its upper face, which pressure is supplied through port 185-O, and that piston 192-O loses its previous control of the position of the hanger. At the same time, as the pressure on the end 277 of upper servo spool 227 increases, the upper piston 192 assumes control of the position of the hanger, so that the torque consumed by the pump is maintained at a constant value, in the manner previously explained. Under these conditions there will be an abutting connection between the lower end 195 of stop 193 connected to control piston 192 through washer 238 to piston 183.

To make up leakage from the system, which for example might occur in the hydraulic machinery being operated, provision is made in the hydraulic system of FIG. 5 for means to introduce additional fluid into the main pump circuit, regardless of the direction of flow through pump 245. This make-up fluid supply system includes the pressure reducing valve 270, which maintains a low pressure in line 272. This pressure is less than the pressure delivered by the pump to line 248 or 250, whichever is the outlet line, but is greater than the pressure in the line which constitutes the pump inlet line. Consequently, if line 148 constitutes the outlet or pressure line, make-up fluid is introduced into the suction line 250 through check valve 275, and check valve 276 blocks the escape of fluid from line 248. When line 250 constitutes the pressure line, fluid is introduced into the system through check valve 276.

It will be noted that the cross center torque limiter is operated by a source of pilot pressure or working pressure, pump 253 in the circuit shown in FIG. 5, whereas the single side limiter previously described was operated solely by the pressure of the pump it controls. The pump 253 and the accompanying control circuitry are provided to supply operating pressure to actuate the pistons 192, 192-O, when the fluid pressure being delivered by the pump 245 is not sufficient to do so, or is too low for best operation, as for example when the hanger is being moved across center or when the pump is starting up.

Hanger positioner—Single side type

In the previously described aspects of this invention, the position of the hanger has been controlled so that the torque delivered to or consumed by a pump or motor is maintained, at a substantially constant value. As has been shown, this is effected through a feed-back system wherein the pressure being delivered by the pump controls pump displacement so that the product of the pressure and displacement is maintained at a substantially constant value.

We have also invented related apparatus whereby the hanger of a variable displacement pump or motor can be positioned to establish any desired displacement in accordance with an independent input pressure signal, so that the hanger position is independent of the system pressure. This pressure signal may be electrically controlled so that displacement can be remotely adjusted by means of an electrical signal. FIG. 6 illustrates hanger positioning apparatus including the features of this aspect of the invention, for a single side translating device which, for purposes of explanation, is assumed to be operated as a pump.

In FIG. 6, the hanger of a variable displacement single side pump which is to be controlled is designated 51. For purposes of description, this pump may be similar to that illustrated in FIG. 1. The housing 61 of the pump in which the hanger 51 is included is fitted with a generally cylindrical block 286 having a bore 287. This block 286 is secured to the housing 61 by a suitable means not shown and a fluid seal 288 is provided between the body 61 and the block 286.

In the bore 287 of block 286, there is fitted a cylindrical sleeve 289 in which a generally cylindrical positioner piston 290 slides. The lower end 292 of positioner piston

290 is engaged with and bears upon the wheel 56 of the hanger 51. A spring 76 loads a plunger 67 upwardly against a wheel 58 on the opposite side of the hanger 51, thereby holding the hanger in engagement with positioner piston 290.

A chamber 293 is defined in sleeve 289 above the upper end of positioner piston 290, and this chamber is closed by a cap 294 which includes a fluid passage 296 that communicates with chamber 293.

The piston 290 has a longitudinally extending slot 298 in which rides a pin 299 secured in the lower part of sleeve 289, thereby preventing the piston 290 from turning about its axis. Also, the piston 290 is provided with a slanting planar cam surface or ramp 300, upon which a cam follower wheel 301 rides. Cam follower wheel 301 is rotatably journaled at one end of a plunger 302. This plunger 302 is received in a transverse bore 303 of body section 304 secured to the side of block 286. A spring 307 bears upon plunger 302 and urges cam wheel 301 into engagement with cam surface 300.

Hydraulic mechanism contained in a block 308 controls the force which is applied to the left end of spring 307. This block 308 includes a bore 309 which is aligned with bore 303 of body section 304. In bore 309 there is secured a sleeve which is identical to the sleeve 209 illustrated in FIG. 4. This sleeve, as well as the grooves and ports which are formed in it, bear the same numbers as the sleeve 209 illustrated in FIG. 4. A servo spool is slidably received in the bore 210 of this sleeve and this servo spool is identical to the servo spool 227 illustrated in FIG. 4, and is therefore similarly numbered. It should be noted, however, that in FIG. 6 the spool 227 is reversed end for end in the bore 210 from the position of the spool in FIG. 4.

A fluid passageway 310 is formed in block 286, body section 304, and in block 308 which provides fluid communication between the chamber 311 in which cam follower wheel 301 resides, at one end, and groove 213 of sleeve 209. A port 312 in block 308 communicates with groove 212 of sleeve 209, and this port 312 is connected by means of a line 314 to passage 296 in cap 294. Another port 315 in block 308 communicates with groove 211 of sleeve 209, and a line 316 is connected to port 315.

A chamber 318 is defined in block 308 at the left end of bore 309 therein, and fluid pressure in this chamber 318 acts upon the end face 277 of servo spool 227. A port 319 communicates with chamber 318, and a line 320 is connected to port 319.

As previously indicated, the hanger positioner illustrated in FIG. 6 controls the position of the hanger 51, and thus the volume of fluid displaced in a single revolution of the pump, in accordance with an input pressure signal. This pressure signal is applied through line 320, and acts on the end face 277 of the servo spool 227. Operating pressure, which may be supplied by a pilot pump, is applied at port 315 through line 316. Fluid in passageway 310 and chamber 311 is essentially at tank pressure, since chamber 311 is connected by slot 298 with the chamber within the pump housing 61 which chamber is substantially at tank pressure.

The position of piston 290 in its sleeve 287 is controlled by the volume of fluid in chamber 293 above its upper end, and the admission of fluid to this chamber 293 is regulated by the servo spool 227, which in turn is controlled by the balance of forces between the fluid force acting on its end face 277 and the compression of spring 307. The spring force varies with the vertical position of piston 290 since the cam follower 301 rides upon the cam surface 300 of piston 290.

In the balanced or steady position, which is illustrated in FIG. 6, the fluid force applied by pressure of fluid in chamber 318 and tending to move the servo spool 227 to the right, is exactly balanced by the force of spring 307, and land 229 closes ports 216. Fluid can neither

flow into or out of chamber 293, and spring 76 holds the hanger fixed in position against face 292 of piston 290. To change the position of the hanger, for example, to decrease pump displacement the volume of fluid delivered by the pump, the pressure applied at port 319 is increased. This adjustment may be done manually, as by means of changing the setting of a pressure control valve, or may be done electrically, as will be explained in relation to FIG. 7. In any event, when the pressure of fluid at port 319 is increased, a larger hydraulic force is applied to spool 227 and the spool is moved to the right. Fluid under pressure in line 316 is thereby enabled to flow to port 312 through the sleeve 209, and from port 312 to chamber 293 through line 314. This fluid is under sufficient pressure to move the piston 290 downwardly. As piston 290 moves downwardly, ramp 300 urges the cam follower wheel 301 to the left, thereby increasing the compression of the spring 307. When the force of the spring balances the increased hydraulic force on the opposite end of the spool 227, and when the land 229 closes ports 216, no more fluid is admitted to chamber 293, and the piston 290 is fixed in position.

By reason of the planar slope of cam surface 300 the fluid force required to move the servo spool 227 against the compression of spring 307 varies approximately linearly with the position of the piston 290, and also approximately linearly with pump displacement. In other words, the system illustrated in FIG. 6 provides control of pump displacement in approximately reverse proportion to the pressure of the control fluid which is supplied to line 320.

FIG. 7 illustrates a hydraulic system whereby the positioner apparatus as illustrated in FIG. 6 is operated in accordance with an electrical signal. In FIG. 7 the single side pump is designated as 322. The outlet port of this pump is connected to a line 323, and fluid under pressure in line 323 is directed to hydraulic machinery upon which work is to be performed, not shown, and to a relief valve 324 which spills fluid in excess of that establishing a pre-selected pressure limit, to a tank or reservoir 325. The intake or suction line of pump 322 is designated as 326, and receives fluid from tank 325.

A pilot pump 327 which, for example, supplies a small volume of fluid at a pressure of about 1000 p.s.i., receives fluid from tank 325 through line 328 and delivers fluid under pressure to a line 329. Line 329 is connected through a flow restrictor 330 to line 320. The pressure in line 329 is limited by a relief valve 333, which spills fluid in excess of that required to establish the pressure at which it is set to tank 325 through a line 334.

The pressure of the fluid in line 320 is regulated or adjusted by a pressure control valve 335. The pressure control valve 335 has an inlet port 336 which is connected to line 320 and an outlet port 337 which is connected to tank line 334. The pressure control valve 335, which is illustrated diagrammatically in FIG. 7, is of the type which establishes a fluid pressure differential between its inlet port 336 and its outlet port 337, in accordance with the magnitude of an electric signal which is supplied to it. One electrically operated pressure control valve which is suitable for this purpose is more fully described in Adams et al. patent application Serial No. 855,629, filed November 27, 1959, entitled "Electric and Fluid Pressure Operated Valve Mechanism." In the valve of that patent application, the pressure differential across the valve is regulated in accordance with and in proportion to the magnitude of an electrical current supplied to an electrical mechanical transducer element of the valve. For example, this current may be regulated by means of a variable resistor which is designated 338 in FIG. 7. It will be understood, therefore, that the pressure of the fluid in line 320 is maintained at a value above tank pressure which is controlled by the magnitude of the electrical current supplied to the valve 335 through resistor 338.

Any difference in pressure between lines 329 and 320 appears across restrictor 330. The pressure of the fluid in line 320, as controlled by valve 335, is applied in chamber 318 (FIG. 6) and supplies the fluid force which acts in opposition to the force of spring 307. As previously explained in relation to FIG. 6, changes in this pressure are reflected as proportionate changes in the volume of fluid delivered through the pump 322. One advantage of this system is that since under steady conditions there is no flow or at most only a very small flow in line 320 to the chamber 318, it is possible to use long lines between the valve 335 and port 319.

If pressure control valve 335 is of the type disclosed in previously identified application Serial No. 855,629, the pressure drop across the valve is proportional to the electrical current supplied to it. Thus, the larger the current supplied to the valve 335, the greater the pressure of fluid in chamber 318, the greater the compression of spring 307 required to offset that pressure, and the greater the movement of positioner piston 290 in the volume decrease direction which is required to supply that compression of the spring 307. Thus, an increase in the electrical current to the valve 335 will be manifested as an inversely proportionate change in the volume of fluid delivered through the pump 322.

Hanger positioner—Cross-center type

As previously explained, the hanger positioner illustrated in FIGS. 6 and 7 is suitable for use with single side pumps or motors. In FIGS. 8, 9 and 10 there is illustrated a hanger positioner including the features of the invention for use with cross-center type pumps or motors. This hanger positioner differs from the single side positioner chiefly in that it includes a longer positioner piston and in the provision of means for centering the hanger in the event of failure of operating pressure.

With reference to FIG. 8, the hanger 51' of a variable displacement cross-center type pump or motor is positioned between a pair of upper and lower assemblies designated respectively by 340 and 341, which are located on opposite sides of the housing 61' and which are provided with movable pistons which engage the wheels 56' and 58' respectively of the hanger 51'.

The lower assembly 341 comprises a cylinder block 343 which has formed in it a stepped cylindrical bore having a section 344 of small diameter and a section 345 of larger diameter. A shoulder 346 is defined between the bore sections 344 and 345, and a port 348 communicates with the bore section 345 in cylinder block 343.

A slidable stop washer 350 resides in bore section 345, and is urged upwardly therein against the shoulder 346 by means of a spring 351. This washer 350 has an enlarged center portion 352 having diagonally extending bores 353 through which fluid can flow from one side of washer 350 to the other. The lower bore section 345 is closed by a cap 354. A cylindrical piston 356 is slidably and sealingly received in the smaller diameter bore section 344, and the upper end of this piston 344 engages the wheel 58' previously referred to.

The assembly 340 on the opposite side of hanger 51' contains hydraulic positioner control mechanism whereby the hanger is positioned in accordance with the magnitude of a pressure signal which is applied to the control mechanism. The assembly 340 includes a cylinder block 358 which is secured to the pump housing 61' and which contains a stepped internal bore having a smaller diameter lower bore section 359 and a larger diameter upper bore section 360. The diameter of the smaller bore section 359 of cylinder block 358 is greater than the diameter of the smaller bore section 344 of the opposite assembly 341. A shoulder 362 is defined between the two bore sections 359 and 360, and the upper bore section 360 is closed by a cap 363. A port 364 communicates with bore section 360, and a slidable stop washer 366, which is similar to washer 350 of assembly 341 but larger in diameter, slides

in the upper bore section 360. This washer 366 is held downwardly toward shoulder 362 by a spring 367. A pair of bores 368 provide for the flow of fluid from one side of the stop washer 366 to the other side thereof.

A positioner piston 370 is slidably received in the lower bore section 359 of assembly 340, and this piston 370 is similar to the positioner piston 290 illustrated in FIG. 6 with the exception that the piston 370 is longer in order to provide for abutting control of the hanger from side to side across the center line of the pump. The positioner piston 370 has an inclined planar cam surface 371 formed on one side which is similar to the ramp 300 of piston 290 illustrated in FIG. 6, but which is longer on account of the greater distance of travel of the piston 370. A cam follower designated generally by 373 is urged against the cam surface 371 by a spring 374.

The compression of spring 374 is determined by hydraulic control mechanisms contained in a block 375. This mechanism in block 375 is shown in FIG. 9, and is the same in all functional respects as the previously described mechanism which is contained in the block 308 illustrated in FIG. 6. The elements of the mechanism contained in block 375 are numbered the same as the corresponding elements in block 308. Thus, block 375 has a bore 309 which is aligned with the cam follower 373, and in this bore 309 there is fitted a sleeve 209 in which there is a slidable servo spool 227. The right end of 228 of this spool 227 bears against a shouldered element 376 which interfits the end of spring 374. Pressure urging the servo spool 227 against spring 374 is applied to the left end 277 of the spool 227 through a port 377 in block 375, which corresponds to the port 319 of the structure in FIG. 6. Groove 212 of sleeve 209 communicates with a port 312 in block 375, groove 211 of sleeve 209 communicates with a port 316, and groove 213 communicates with a fluid conduit 310 which communicates with the interior of the housing 61', which is at substantially tank pressure. Port 312 of block 375 is connected to port 364 of the upper bore section 360 by a line 378.

In the operation of the cross center positioner illustrated in FIG. 8, fluid under pressure, which preferably is supplied by a pilot pump, is applied through port 348 of the lower assembly 341. Fluid below piston 356 urges the piston 356 upwardly with a force equal to the piston cross sectional area multiplied by that pressure. When the lower end of piston 356 is below shoulder 346 in bore 344, the force of spring 351, pushing stop washer 350 upwardly, is also applied to the piston 344; if the lower end of piston 356 is above shoulder 346, then the fluid force alone acts on it inasmuch as the shoulder 346 limits the stop washer 350 from further upward movement. Shoulder 346 is so located relative to the center line of the pump that when the lower end of piston 356 is just aligned with the shoulder 346, the upper end of piston 356 will be positioned to hold the hanger 51' in its center position.

Fluid under the same pressure as at port 348 is also supplied to port 316 of the upper assembly 340. When the servo spool 227 is in the position shown in FIG. 9, in which its central land 229 closes ports 216, this fluid cannot flow through the ports 216. Movement of the spool 227 from the centered position shown is controlled by the balance of forces between the controlled fluid force applied to its end face 277 and the compression of spring 374. If the control pressure on face 277 of spool 227 is increased, then the spool moves to the right, so that land 229 opens ports 216 and fluid under pressure at ports 316 flows to port 312. From port 312, this fluid flows through line 378 to port 364 in bore 360. This fluid under pressure in bore 360 applies a downward force to piston 370 which is equal to the pressure times the area of the piston 370; because this area is greater than the area of the opposing piston 356, on which the same pressure acts, the hanger 51' is moved

downwardly. The magnitude of the pressures applied to port 364 is sufficient to overcome the additional resistance of the spring 351 when the hanger is on the lower side of center position. As the hanger moves downwardly, ramp 371 moves the cam follower 373 to the left, increasing the compression of spring 374, and ultimately balancing the forces on spool 227 so that the spool is centered with land 229 closing ports 216. At this point the downward movement of piston 370 stops, and the fluid is trapped above piston 370 in bore 360.

The purpose of the stop washers 366 and 350 in assemblies 340 and 341 respectively is to center the hanger in the event of a failure of pressure. If the pressure applied to ports 348 and 364 fails, then the fluid forces acting on the opposing pistons 356 and 370 disappear. The springs 367 and 351 are so arranged that they will then center the hanger, moving washers 366 and 350 into abutment with the shoulders 362 and 346 respectively.

If a reduced control pressure is applied through port 377 to the end face 277 of spool 227, spring 374 will move the center land 229 of the spool to the left, thereby providing fluid communication between bore 312 and passageway 310, which is at tank pressure. Under these conditions, fluid above the upper end of piston 370 will be released to tank through port 364, line 378, port 312 and passageway 310, and the piston 359 will be moved upwardly by the force applied to the opposite piston 356. As this occurs the compression of spring 374 is reduced, and the upward motion of the hanger will cease when the fluid forces and the mechanical spring forces on servo spool 227 are balanced and land 229 closes ports 216.

FIG. 10 illustrates a hydraulic system wherein the control pressure applied at port 377 to position the hanger can be adjusted electrically, similar to the manner in which the control pressure can be adjusted in the previously described system shown in FIG. 7 in connection with single side pumps and motors. In the circuit or system shown in FIG. 10, the cross center pump is designated by 379, and this pump 379 has one port connected to a line 380 and the other port connected to a line 381. Each of the lines 380 and 381 is connected to hydraulic machinery to which fluid under pressure is supplied alternately depending on the direction of flow of fluid through the pump 379. The lines 380 and 381 are connected by a dual or two direction relief valve 249 which may be of the type disclosed in previously identified application Serial No. 171,135.

A small volumetric capacity pump 382 receives fluid from a reservoir 383 and delivers it under pressure to a line 384. Line 384 is connected to tank 383 through a relief valve 386 which discharges to the tank fluid in excess of that required to maintain the preselected pressure, which pressure is great enough to move the pistons 370 and 356. Line 384 is connected to port 348 of the lower assembly 341, and to port 316 of the block 375. Line 384 is also connected through a flow restrictor 387 to a line 388 which is connected to control pressure port 377. An electrically operated pressure control valve 389 has its inlet port connected to line 388, and its outlet port is connected to tank 383 through a line 390. This pressure control valve 389 is preferably thought not necessarily of the type described in previously identified application Serial No. 855,629.

Make-up fluid is introduced into the main pump circuit to replace any losses through a pressure reducing valve 392, which may be of the type described in previously identified Patent No. 2,747,606. This pressure reducing valve 392 has its inlet port connected to line 384 by a line 393 and supplies fluid at a relatively low pressure, for example 50 p.s.i., to a line 394. Valve 392 has a tank port which is connected by line 395 to tank 383. Line 394 is connected to a check valve 396 which permits flow to line 380, and line 394 is also connected to a check valve 397 which permits flow to line 381. By these means fluid will be supplied into whichever of lines

380 or 381 constitutes the inlet line of the pump 379 at any given time, to make up system losses, and fluid will be prevented from being lost through the outlet line of the pump.

In the operation of the system illustrated in FIG. 10, the electrically controlled pressure control valve 389 regulates the pressure of fluid in line 388 in accordance with the electrical current supplied to the valve 389. As this current is increased the pressure in line 388 also increases. The pressure in line 388 may be different from the pressure of fluid in line 384, by reason of the restrictor 387, flow across which establishes the pressure differential between the two lines 384 and 388. The pressure of fluid in line 388 governs the hydraulic force supplied in opposition to the force of spring 374 acting on the spool 227 and thereby determines the admission or release of fluid from the chamber above piston 370.

The greater the pressure applied to spool 227, the greater will be the movement of piston 370 in the downward direction; with the hanger in its uppermost position, the pump displacement will be increased as the hanger 51' moves downwardly to null position, and then displacement will increase, but the flow will be in the opposite direction. It should be noted that displacement is not proportional to the current supplied to the valve 389, inasmuch as displacement drops substantially to zero as the hanger moves across center. However, for each current applied to valve 389, the system of FIG. 10 establishes a definite displacement and a definite direction of flow through the pump.

Combined torque limiter and hanger positioner—Single side type

We have previously described the apparatus we have invented for controlling the torque supplied to a variable displacement fluid translating device. We have also described the related apparatus we have invented for independently controlling the displacement of a variable displacement translating device. The torque limiter means and displacement control may also be used in combination with each other so that the torque of a variable volume device is prevented from exceeding a predetermined maximum and so that until maximum torque is reached displacement can be controlled by an independent pressure signal. In accordance with this aspect of the invention, when the torque being delivered to or consumed by the device tends to exceed a preset magnitude, the torque limiter automatically overrides the hanger positioner and assumes control of the hanger so that the torque limit will not be exceeded, regardless of the displacement which the hanger positioner had previously established.

This combined torque limiter and hanger positioner apparatus is illustrated in FIGS. 11 to 18 in connection with a variable displacement single side pump.

In this apparatus, as shown in FIG. 11, the hanger 51 of a single side pump, not shown in detail and which may be conventional or similar to that shown in FIG. 1, is urged in the upward (displacement increase) direction by means of a plunger 68, which is actuated by a spring 76. This plunger 68 may be similar to that shown in FIG. 1.

The action of spring 76 and plunger 68 on the hanger 51 is opposed by an assembly designated generally by 401 which is mounted on housing 61 opposite plunger 68. The assembly 401 includes a hanger positioner or control piston 402 which slides in a cylinder 403 secured to housing 61. Piston 402 has an inclined planar cam surface 404 on one side, and in this respect the resemblance between the piston 402 and the piston 370 shown in FIG. 8, relating to a cross-center positioner, will be seen. A spring loaded cam follower rides on the cam surface 404, and this cam follower is similar to the cam follower 373 illustrated in FIG. 8 and bears the same number. The cam follower 373 of the assembly shown in FIG. 11 coop-

crates with hydraulic positioner control mechanism contained within a block which is identical in all respects to the block 375 previously illustrated and described in connection with FIG. 8. This block 375 includes a sleeve 209 in which slides a servo spool 227. The details of sleeve and spool are illustrated in FIGS. 13 and 17, and are substantially identical to the mechanism previously described in relation to FIG. 9, and are similarly numbered.

At the upper end of the cylinder 403, there is provided torque limiter mechanism designated generally by 405. This mechanism 405 is substantially identical to the structure 188 in FIG. 3 which has previously been described, and its elements are numbered similarly to those of that structure. This structure 188 includes a torque limiter piston 192 having a stop 193 projecting from its lower face. Stop 193 under certain conditions comes into abutting or drive relation with the piston 402, depending upon the vertical position of piston 192 with respect to piston 402. The torque limiter piston 192 also has a cam surface 196, upon which rides a cam follower wheel 199. The vertical position of the piston 192 is controlled hydraulically by means of apparatus contained in a hydraulic control cap 189, the internal elements of which are illustrated in FIGS. 12 and 16. The mechanism in cap 189 is substantially identical to the mechanism previously illustrated and described in relation to FIG. 4, and the parts of the cap mechanism illustrated in FIG. 12 bear the same number, followed by -a, as their counterparts in FIG. 4.

The cam follower wheel 199 reciprocates a piston 200, which in turn moves a rocker arm 202 having a wheel 236 at one end which bears upon piston 234-a. This piston 234-a is connected to a spring 235-a the other end of which bears upon a servo spool 227-a and moves the spool in the manner previously described.

The chamber 407 which is defined between the lower face of piston 192 and the upper end of piston 402 is connected to port 312 of block 375 by means of a line 408.

A hydraulic system including a single side variable displacement pump equipped with the combined hanger positioner and torque limiter 401 is shown in FIG. 14. In this figure, the pump is designated by 409 and has an intake line 410 and an outlet line 411 to which the pump 409 supplies fluid under pressure. The pump outlet line 411 is connected by means of a branch line 412 to port 233-a of the hydraulic control cap 189. The intake line 410 receives fluid from a reservoir 414. Port 224-a of the cap structure 189 is also connected to tank 414 by means of a line 415.

The hydraulic hanger positioner and torque limiter mechanism 401 requires a supplementary source of fluid pressure for best operation under all conditions, for example, when the pump is just starting up, and such fluid is supplied by means of a pilot pump 416 which has its outlet side connected to a line 417. Line 417 is connected to port 225-a of the cap structure 189 and also to port 316 of the structure contained in block 375. Line 417 is connected through a flow restrictor 419 to a line 420, and line 420 is connected to the port 377 of block 375. The pressure in line 420 is controlled by an electrically operated pressure control valve 421 which may be similar to the electro-mechanical transducer operated pressure control valve described in Adams patent application Serial No. 855,629, previously referred to. This pressure control valve 421 has an inlet port which is connected to line 420 and an outlet port which is connected to tank 414 by a line 422. The pressure which valve 421 maintains in line 420 varies in accordance with the magnitude of an electric current supplied to the transducer of valve 421, not shown, through an electric circuit 423 which includes a variable resistor for controlling the magnitude of the current.

In the operation of the combined torque limiter-hanger positioner apparatus and system illustrated in FIGS. 11

to 18, the torque limiter mechanism prevents the pump input torque from exceeding a predetermined limit. Below the preselected limit, the position of the hanger, and therefore pump displacement, are controlled by the hanger positioner piston 402 which in effect isolates the hanger 51 from the operation of the torque limiter piston 192, except when the torque tends to become excessive.

FIGS. 11, 12 and 13 illustrate the positions of the elements of the apparatus when the pump torque is not excessive, that is, when the positioner is in control of the displacement changing means and when the torque limiter is not overriding it. FIGS. 15, 16 and 17 show the respective positions of the apparatus when the torque tends to exceed the limiting value and the torque limiter starts to come into operation, and FIG. 18 shows the relation of the elements of the apparatus on the torque limiter piston assumes direct control of the hanger.

The fluid pressure being delivered by the pump 409 to line 411 is applied through line 412 and port 233-a (FIG. 12) to the left end 277-a of spool 227-a of the torque limiter. This pressure operates the servo spool 227-a to position torque limiter piston 192 in the manner previously described. At any pressure developed by the pump, the lower end of stop 193 defines a displacement limit above which piston 402 cannot move. The piston 192 moves upwardly and downwardly with system pressure changes, but so long as the displacement established by the positioner piston is not excessive at the pressure being developed, the torque limiter piston 192 does not abut or control the positioner piston 402, which moves below it and thereby isolates the hanger from changes in its position.

Under these conditions, positioner piston 402 is controlled by the positioner, and will move only in response to changes in the control pressure signal. For example, a system pressure increase will move piston 192 downwardly; fluid trapped in chamber 407 will initially transmit the force applied to piston 192 to piston 402 and will start to move that piston downwardly. However, slight downward movement of piston 402 will cause a net outward force to be applied to spool 227 of the positioner, moving the spool to the left and releasing fluid in chamber 407 as piston 192 continues to move downwardly. The positioner piston 402 will itself remain fixed in position. Similarly, a decrease in system pressure will initially reduce the pressure in chamber 407; piston 402 will start to move upwardly, which will cause the positioner servo spool 227 to admit additional fluid to chamber 407, to lift piston 192 and prevent piston 402 from moving. Only when the positioner tends to establish a displacement which would cause the torque to be excessive at the pressure being delivered, does piston 192 limit the movement of piston 402.

From what has previously been explained, it will be understood that the compression of spring 235-a of the torque limiter may be regulated to provide different torque (or horsepower) limits by changing the length of the piston 200, to which cam follower 199 is connected, for example by means of an adjustable stop mechanism such as is illustrated in FIG. 1; alternatively, the length of stop 193 may be made adjustable to provide for establishing different limiting values.

When the hanger is in a stable position, that is, when it is neither being moved upwardly nor downwardly, land 229 of the hanger positioner apparatus (FIG. 13) closes ports 216 and the fluid under pressure at port 316 cannot flow through ports 216. Under these conditions the force applied to the hanger positioner servo spool 227 by spring 374 exactly balances the fluid force acting on the left end 277 of spool 227, which pressure is controlled by the pressure control valve 421 and which is applied thereto through line 420. Thus, fluid in chamber 407 above the upper end of piston 402, is trapped in that chamber, ports 216 being blocked by land 229 as previously explained, the piston 402 is held in a predeter-

mined position with respect to the hanger, and the hanger 51 is held fixed between the piston 402 and the plunger 68. This condition is illustrated in FIG. 11.

To move the hanger in a downward direction and thereby decrease displacement, the electric current supplied to the electromechanical transducer of pressure control valve 421 through the electrical circuit 423 is increased, so that the pressure maintained by valve 421 in line 420 is also increased; this increased pressure supplies a greater force to the left end 277 of spool 227 of the hanger positioner control, and this increased fluid force moves the spool 227 to the right against the action of spring 374. Land 229 now opens ports 216 and fluid supplied from the pump 416 to port 316 of the hanger positioner apparatus flows to ports 216 and through port 312 and line 408 into the chamber 407 above the piston 402. This fluid pressure forces the hanger piston 402 downwardly, moving the hanger 51 in the displacement decrease direction. Piston 192 does not move in response to this pressure. As the piston 402 moves downwardly, the cam surface 404 moves the cam follower wheel 373 outwardly, increasing the compression, of spring 374 until the spring force exactly balances the hydraulic force on the spool 227 and land 229 again closes ports 216. The hanger will be maintained in this position so long as the torque supplied to the pump does not exceed the value at which the torque limiter piston 192 abuts piston 402 and overrides the positioner.

Correspondingly, when it is desired to increase the volume of fluid delivered by the pump, the fluid pressure in line 420 is reduced, by reducing the electrical current to the valve 421. The spool 227 moves then to the left under the relatively greater force of spring 374, and fluid in chamber 407 above the piston 402 flows out of that chamber through line 408, ports 216, and passageway 310 to tank 414, through the interior of the pump. As the piston 402 moves upwardly, the compression of spring 374 is decreased as the cam surface 404 permits the cam follower 373 to move outwardly, and the movement of the piston 402 stops when the decreased pressure exactly balances the hydraulic pressure at the opposite end of the spool 227. In these respects, so long as the torque delivered to the pump shaft is not in excess of the predetermined limit, the operation of the hanger positioner is virtually identical to the operation of the hanger positioner previously described in relation to FIGS. 6 and 7.

As previously explained, normally stop 193 of the torque limiter piston 192 does not abut piston 402, and movement of piston 192 in response to pressure variations are not transmitted to piston 402 and hanger 51. However, when the pressure rises to a value such that the maximum displacement permitted by the torque limiter is less than the displacement which the positioner tends to establish, or when the positioner is actuated to supply a greater displacement than permissible at the pressure being developed, then the torque limiter stop 193 abuts piston 192, overrides the positioner, and assumes control of piston 402 and hanger 51, as shown in FIGS. 15 to 18.

If system pressure increases when stop 193 is spaced above piston 402, fluid in chamber 407 transmits the force applied to piston 192 to piston 402. Piston 402 is thereby caused to move downwardly. (See FIG. 15.) As the piston 402 starts to move downwardly, the compression of spring 374, acting on the hanger positioner servo spool 227 increases, moving the land 229 of that spool to the left, and opening a flow path between ports 216 and tank through passage 310, so that fluid in chamber 407 is released to tank (FIG. 17). As this occurs, if the torque is excessive, piston 192 moves downwardly until stop 193 directly abuts the upper end of piston 402, and the torque limiter piston 192 then pushes the hanger piston 402 downwardly (FIG. 18). As the piston 192 moves downwardly, its cam surface 196 swings the rocker arm 202 clockwise, so that the compression of spring 235-a is increased. When the force applied by spring 235-a to

spool 227-a exactly balances the then pressure on the opposite face 277-a and land 229-a closes ports 216-a, flow of fluid into chamber 221-a stops and the torque limiter piston 192 stops.

The plunger 68 holds the hanger 51 against piston 402, regardless of the position of that piston and a stop, not shown, prevents the hanger 51 from movement to the opposite side of the center.

When the hanger 51 is positioned as illustrated in FIG. 18, the which the piston 192 abuts piston 402, if the pressure being delivered by pump 409 to port 233-a decreases, the chamber 221-a above piston 192 is connected to tank and the force of spring 76 acting on plunger 68 pushes both pistons 402 and 192 upward. Since the torque limiter piston 192 is not then controlled by fluid force, the hanger positioner again comes into operation, and as the piston 402 moves upwardly the compression on spring 374 of the hanger positioner is decreased, permitting spool 227 to move to the right so that fluid flows from port 316 into chamber 407. The upward movement of piston 402 is stopped when the compression of spring 374, as determined by the vertical position piston 402, balances the fluid control force then applied to the spool 227. In this manner, the positioner piston 402 transmits the movements of the limiter piston when torque is excessive, and under normal conditions independently operates the displacement changing means.

Combined torque limiter and hanger positioner—Cross center type

As previously noted, the combined torque limited and hanger positioner illustrated in FIGS. 11-18 is for use with a single side pump. In FIGS. 19 and 20 there is illustrated a combined torque limiter and hanger positioner for use with cross center translating devices.

With reference to FIG. 19, the combined torque limiter and hanger positioner which is adapted for use with cross-center type fluid pressure translating devices includes an upper assembly 430 and a lower assembly 431 on opposite sides of the pump housing 61. These assemblies 430 and 431 present opposed aligned pistons which engage the hanger 51'.

The upper assembly 430 is nearly identical to the assembly 401 which has been previously described in connection with the single side torque limiter and positioner illustrated in FIG. 11, and corresponding parts in these two figures are similarly numbered. However, it is pointed out that in the assembly 430 illustrated in FIG. 19, the ramp or cam surface 432 of the hanger positioner piston 402 is relatively elongated and is more acutely angled with respect to vertical than the cam surface 404 of the assembly illustrated in FIG. 11, to provide for camming the follower 373 as the piston 402 moves from one side across center to the other side. The length of cam surface 432 is approximately twice that of the cam surface 404.

Also, in the cross center device shown in FIG. 19, the bore 433 in which the hanger positioner piston 402 slides is a stepped bore and has an enlarged upper portion 434 which meets the lower bore portion at a shoulder 436. In this enlarged bore portion 434 there is an axially movable stop washer 437 which has a diameter greater than the diameter of the lower, smaller portion of bore 433. This stop washer 437 has an enlarged or thickened central portion 438, and a diagonally extending bore 439 establishes fluid communication from one side of the stop washer 437 to the other. A spring 440 urges the stop washer 437 downwardly in bore 434 toward shoulder 436. Other than in these respects, the upper assembly 430 is identical to the assembly 401 previously described.

The lower assembly 441 on the opposite side of hanger 51' is similar in many respects to the lower assembly 176 illustrated in FIG. 3 in connection with the cross-center torque limiter previously described, and the elements of the lower assembly illustrated in FIG. 19 bear the same numbers as the corresponding elements of the assembly

176. It should be noted, however, that piston 192-O of assembly 431 is sealed in cylinder 441 in which it slides by suitable means such as O-ring 442 which is in sliding, sealing contact with stop 193-O extending upwardly from piston 192-O. O-ring 442 is received in a groove in the shoulder 443 between piston cylinder and the chamber 444 in which the spring 242-O is contained. Also, a passageway 447 connects the upper end of cylinder 441 with the interior of housing 61', which is at substantially tank pressure. By these means it will be seen that the cylinder 441 is sealed by O-ring 442 to fluid pressure in chamber 444, and that fluid in cylinder 441 above the upper end of piston 192-O is released to tank through passageway 447.

In the operation of the cross-center combined torque limiter and hanger positioner illustrated in FIG. 19, a regulated or controlled pressure signal is supplied to the hanger positioner control mechanism in block 375 which regulates the admission of fluid under pressure to chamber 497 above piston 402.

Torque limiter control mechanism 450 of the upper assembly 430 limits the torque delivered to the pump when the hanger 51' is on the upper side of the center line of the translating device, and the torque limiter control mechanism 451 of the lower assembly 431 limits the torque delivered to the pump when the hanger 51' is on the opposite or lower side of center. In this regard the operation of the two torque limiters 450 and 451 is generally similar to the operation of the cross-center torque limiter apparatus previously described in relation to FIGS. 3-5. However, the torque limiters 450 and 451 do not control the piston of the hanger at all times; rather they individually determine maximum torques which will be delivered to the translating device at any given time, and below the limits they establish the position of the hanger on either side of center is controlled by a pressure signal which is supplied to the hanger positioner. In this regard the operation of the hanger positioner is similar to the operation of the cross-center hanger positioner previously described in relation to FIGS. 8-10.

FIG. 20 illustrates a hydraulic circuit or system for operating a variable displacement cross-center type pump equipped with the combined torque limiter and hanger positioner illustrated in FIG. 19. In FIG. 20 the pump is designated by 449. The ports of the pump are numbered 452 and 453 and are connected to fluid lines 454 and 455 respectively. The lines 454 and 455 are connected to hydraulic machinery upon which work is to be performed, which is not shown. A suitable dual operating or two directional relief valve 457 is connected between the lines 454 and 455 to by-pass fluid in excess of that required to maintain a predetermined pressure directly from the outlet side of the pump to the inlet side.

Line 455 is connected by a line 458 to the port 233-O of the lower assembly 431. Line 454 is connected by a line 459 to the corresponding port 233-a of the upper assembly 430. A small volumetric capacity pump 461 receives fluid through an intake line 462 from a tank 463 and discharges fluid under pressure to a line 464. A relief valve 465 prevents the pressure in 464 from exceeding a predetermined limit, spilling excess fluid to tank 463. Line 464 is connected by a line 467 to port 225-a of the upper assembly 430, and line 467 is also connected to port 316 of the hanger positioner block 375. Line 467 is connected by a branch line 468 to port 185-O of the lower assembly 431, and by another line 469 to port 225-O of the lower assembly 431. Port 224-O of the assembly 431 is connected to tank 463 by a line 471, and similarly port 224-a of the upper assembly 430 is connected to tank by a line 472.

Line 467 is connected through a flow restrictor 474 to a line 475 which is connected to port 377 of block 375. The pressure of fluid in line 475 is controlled by an electrically operated pressure control valve 476 which controls the pressure in line 475 in proportion to an electrical

input supplied to it by an electric circuit 477. The drain port of pressure control valve 476 is connected to tank by line 478.

Make-up fluid to replace any loss in the machinery on which work is being performed or elsewhere is introduced into the main pump system through a pressure reducing valve 480 which has its inlet port connected to line 467. The outlet port 481 of pressure reducing valve 480 is connected through a check valve 482 to line 454, check valve 482 permitting flow to but not from line 454. Outlet port 481 of pressure reducing valve 480 is connected to a check valve 483 to line 455, check valve 483 permitting flow to but not from line 455. The pressure reducing valve 480 maintains a low pressure in line 481 and fluid will be introduced from that line into whichever of lines 454 or 455 constitutes the pump suction line at any given time.

In the hydraulic circuit illustrated in FIG. 20, fluid at the pressure developed by pump 449 is applied either to port 233-a of the upper assembly 430 or to port 233-O of the lower assembly 431, depending upon whether port 452 or 453 is the pressure port. As previously explained, when the hanger 51' is on any given side of center, the opposite torque limiter control mechanism 450 or 451 is inoperative and its piston 192 or 192-O is under no fluid pressure acting to move it toward the hanger. The torque limiter control mechanism which is connected to the pressure side of the pump 449 moves with system pressure changes but does not abut or drive the positioner piston unless torque tends to become excessive. When the torque delivered by the pump 449 exceeds this limiting value, then the torque limiter piston abuts and drives its associated positioner piston in the displacement decrease direction, in the manner previously explained.

At all times fluid is supplied under pressure from pump 461 to port 185-O of the lower assembly 431, and this fluid pressure acts on the cross-sectional area of the piston 183-O to hold that piston upwardly in engagement with the hanger 51', thereby tending to move the hanger in upward direction. However, the fluid pressure in chamber 444 is prevented from acting on the upper face of piston 192-O by O-ring 442.

Thus, assuming that the hanger is on the upper side of center, the torque will be prevented from becoming excessive by the control mechanism 450 of the upper assembly 430; and if the torque tends to exceed the limit established by the torque control mechanism of that assembly, piston 192 moves downwardly, overriding the positioner which tends to control the position of piston 402. The cross-sectional area of piston 192 is greater than the cross-section of piston 183-O, and this fluid force therefore moves the hanger 51' downwardly. Fluid in chamber 444 is backed out and is released to tank through valve 465.

If port 452 is the pressure port, and the torque delivered by the pump 449 tends to become excessive, the lower torque control mechanism 451 comes into control and its piston 192-O moves into abutting contact with piston 183-O. The total force on piston 183-O is then the net force on piston 192-O plus the force of fluid in chamber 444 acting directly on the lower face of piston 183-O. The sum of these forces is greater than the forces acting on piston 402, and a net force acts in the upward direction to move the hanger toward center. There is no fluid pressure in cylinder 441 acting downwardly on the piston 192-O because fluid above piston 192-O is released to the pump interior through line 447.

In the event of failure of pump 461 operating pressure, the two springs 242-O and 440 apply equal and opposite centering forces to pistons 183-O and 402 respectively, moving the hanger to center position.

From the foregoing, it will be seen that we have invented apparatus for use with a variable displacement fluid translating device, whereby the fluid displaced by the device each revolution is controlled by a pressure operated piston.

This piston has a cam surface formed on it, and is linked through a cam follower engaging its cam surface and a spring with a servo valve which controls the application of motive fluid for moving the piston. The cam follower compresses the spring which thereby tends to operate the servo valve. The magnitude of the spring force varies with the position of the piston and with the displacement of the translating device. The mechanical or elastic force applied to the servo valve by the spring is opposed by a fluid force tending to actuate the servo valve in the opposite direction. Depending upon the type of control over fluid volume which the apparatus is intended to provide, this fluid pressure may either be equal to the system pressure established by the device, or may be an independent pressure signal. When the fluid force exceeds the elastic mechanical force, the servo valve is actuated to move the piston in one direction, and when the mechanical force exceeds the fluid force, the servo valve is actuated to move the piston in the opposite direction. As the piston moves, the elastic force is changed accordingly, bringing it nearer to the fluid force, until the elastic force equals the fluid force, whereupon the servo valve is closed and the piston ceases to move.

While we have described the preferred form of our invention, it will be obvious that the principles of the invention are not limited to such embodiment alone, but may be incorporated in other modifications and variations in accordance with the following claims.

We claim:

1. The combination comprising,
 - a cross-center fluid pressure translating device having two ports and a displacement varying member shiftable in opposite directions to vary displacement and flow between said ports,
 - a first torque limiter assembly on one side of said member, said first torque limiter assembly comprising,
 - piston means for moving said member in one direction and for limiting its movement in the opposite direction,
 - said piston means including a cam surface, the shape of said cam surface reflecting the graphical interrelation between pressure, volume and torque,
 - servo means for moving said piston means in said one direction to selectively position said member,
 - said servo means including a movable valve member which controls application of motive fluid through said servo means to said piston means, said movable member having a face thereof, disposed to pressure,
 - an elastic cam follower means engaging said cam surface and applying an elastic force opposing fluid force acting on said face of said movable member, the magnitude of said elastic force increasing in inverse proportion as said displacement decreases,
 - a second torque limiter assembly substantially identical to said first assembly, said second assembly being located on the opposite side of said displacement varying member for shifting said displacement varying member in the direction opposite that of the first assembly,
 - means applying fluid at the pressure at the said respective ports to the respective movable members of said assemblies tending to move said movable member to apply fluid to move said piston means,
 - means supplying motive fluid to said servo means, and opposed spring means urging said displacement varying member toward each other.
2. The combination comprising,
 - a variable displacement fluid translating device, said translating device having a movable displacement control the position of which establishes the displacement of said device,
 - a first piston movable in response to pressure applied thereto for changing the position of said displacement control,

- a cam surface moving in response to movement of said control,
 - valve means shiftable to admit and release fluid under pressure for moving said piston,
 - elastic cam follower means engaged with said cam surface and supplying an elastic force tending to shift said valve means in one direction, the magnitude of said force varying with the position of said piston,
 - means supplying a controlled pressure which acts in opposition to the force supplied by said cam follower means and which tends to shift said valve means in the opposite direction,
 - a second piston movable in response to pressure applied thereto into abutting relation with said first piston for moving said first piston,
 - a cam surface formed on said second piston and corresponding to the relation between pressure, displacement and torque of said device,
 - second valve means shiftable to admit and release fluid under pressure for moving said second piston,
 - second elastic cam follower means engaged with said cam surface of said second piston and supplying an elastic force tending to shift said second valve means in one direction, the magnitude of the last mentioned force varying with the torque being developed by said device,
 - means applying fluid at the pressure developed by said device in opposition to the force supplied by said second cam follower means,
 - said first piston normally controlling the position of said displacement control in accordance with said controlled pressure,
 - said second piston engaging said first piston and moving same when the torque developed by said device tends to exceed a preestablished value, and means holding said displacement control constantly in contact with said first piston.
3. The combination comprising,
 - a variable displacement fluid translating device, said translating device having a movable displacement control the position of which establishes the volume of fluid passing through said device,
 - a first piston movable in response to pressure applied thereto for changing the position of said displacement control,
 - positioner means applying pressure to said piston for positioning said displacement control,
 - a second piston aligned with said first piston and movable in response to pressure into abutting relation with said first piston for moving said first piston,
 - said second piston having a cam surface formed longitudinally thereon, the shape of said cam surface reflecting the graphical interrelation between the pressure, displacement and torque of said device,
 - servo means for moving said second piston toward said first piston,
 - means supplying motive fluid to said servo means,
 - said servo means including a movable valve member which controls application of said motive fluid through said servo means to said second piston, said movable member having a control surface face disposed to pressure,
 - means applying fluid at the pressure established by said device to said movable member tending to move said movable member to apply fluid to move said second piston,
 - cam follower means elastically engaging said cam surface and applying an elastic force opposing the fluid force acting on said face of said movable member, the magnitude of said elastic force increasing in inverse proportion as said displacement decreases,
 - said positioner means normally positioning said displacement control, said second piston overriding said

positioner means when said torque tends to exceed a predetermined limit,
and yieldable means holding said displacement control in engagement with said first piston.

4. The combination comprising,

a variable displacement fluid translating device, said translating device having a movable displacement control the position of which establishes the displacement of said device,

a first piston movable in response to pressure applied thereto,

valve means shiftable to apply fluid under pressure to move said piston, pressure acting on said valve means tending to shift said valve means in one direction, a cam surface moving with said piston,

cam follower means riding on said cam surface and connected through a spring to said valve means,

said cam follower means supplying a force to said spring tending to shift said valve means in the direction opposite to the direction in which pressure acting on said valve means tends to shift said valve means,

said cam surface having a contour reflecting the interrelation between the displacement, pressure and torque of said device and which changes the magnitude of the force applied to said valve means by said cam follower means in accordance with the displacement of said device,

a second piston movable between said first piston and said displacement control for moving said displacement control, said first piston being movable into drive relation with said second piston for moving said second piston and displacement control,

and means holding said second piston in a predetermined position when said first piston is not in driving relation with said second piston.

5. The combination comprising, a cross-center type fluid pressure translating device having a displacement varying member shiftable in opposite directions to vary displacement,

a piston for moving said member in one direction and for limiting its movement in the opposite direction, said piston having a cam surface formed longitudinally thereon,

means urging said member in said opposite direction and holding said member against said piston,

servo means for moving said piston in said one direction to selectively position said member on either side of the center line of said device,

means supplying motive fluid to said servo means,

said servo means including a movable valve member which controls application of said motive fluid through said servo means to said piston, said movable member having a face thereof disposed to pressure,

means applying fluid at a controlled pressure to said movable member tending to move said movable member to apply fluid to move said piston,

a spring tending to move said movable member oppositely to said controlled pressure acting thereon,

cam follower means engaging said cam surface and stressing said spring with a force which changes as displacement changes,

and means for controlling the pressure of fluid applied to said movable member.

6. The combination comprising, a cross-center type fluid pressure translating device having a displacement

varying member shiftable in opposite directions to vary displacement,

a piston for moving said member in one direction, said piston having a cam surface formed longitudinally thereon,

servo means for moving said piston in said one direction to selectively position said member on either side of the center line of said device.

means supplying motive fluid to said servo means,

said servo means including a movable valve member which controls application of said motive fluid through said servo means to said piston, said movable member having a face thereof disposed to pressure,

means applying fluid at a controlled pressure to said movable member tending to move said movable member to apply fluid to move said piston,

a spring tending to move said movable member oppositely to said controlled pressure acting thereon,

cam follower means engaging said cam surface and stressing said spring with force changing linearly with the position of said displacement varying member,

means for changing the controlled pressure of the fluid applied to movable member,

and a pair of opposed springs urging said displacement varying member toward center position, said piston normally overriding said springs.

7. The combination comprising, a cross-center type fluid pressure translating device having a displacement varying member shiftable in opposite directions to vary displacement, a piston for moving said member in one direction and for limiting its movement in the opposite direction,

said piston having a cam surface formed longitudinally thereon,

means urging said member in said opposite direction and holding said member against said piston,

servo means for moving said piston in said one direction to selectively position said member on either side of the center line of said device,

means supplying motive fluid to said servo means,

said servo means including a movable valve member which controls application of said motive fluid through said servo means to said piston, said movable member having a face thereof disposed to pressure,

means applying fluid under pressure to said movable member tending to move said movable member to apply fluid to move said piston,

a spring tending to move said movable member oppositely to said controlled pressure acting thereon,

cam follower means engaging said cam surface and stressing said spring with a force which changes continuously as said displacement changes,

and means including an electrohydraulic pressure control valve for controlling said pressure applied to said movable member in accordance with an electrical signal.

References Cited by the Examiner

UNITED STATES PATENTS

2,283,321 5/1942 Doe ----- 103—1

LAURENCE V. EFNER, *Primary Examiner*.