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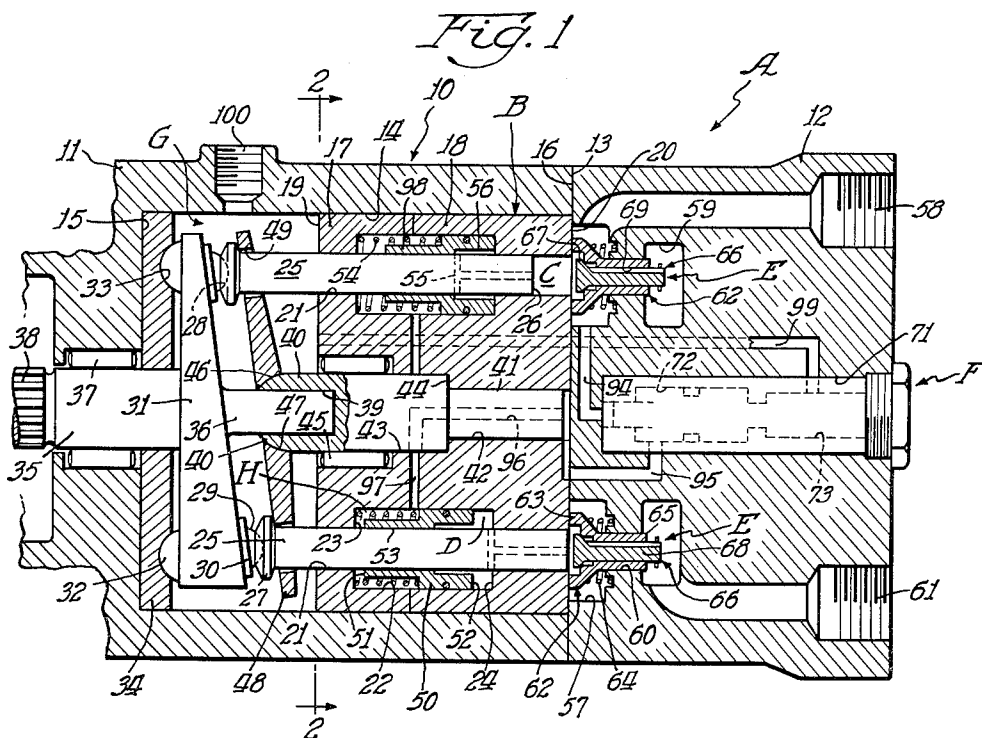
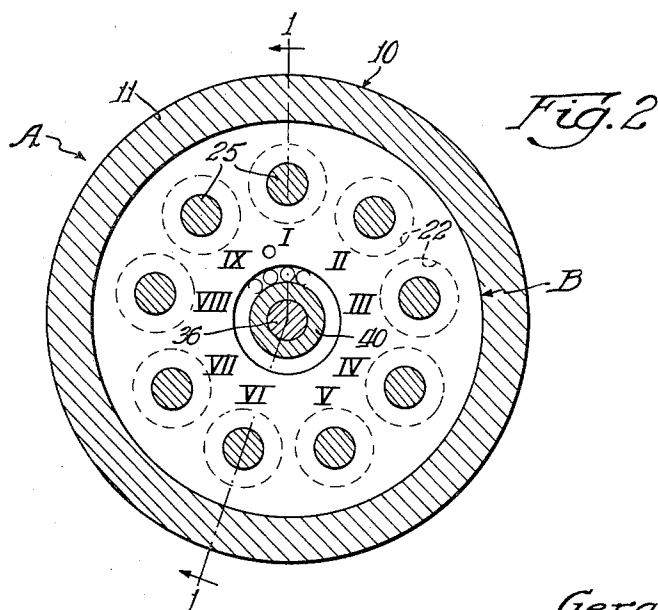
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VARIABLE DISPLACEMENT HYDRAULIC APPARATUS

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3 Sheets-Sheet 1



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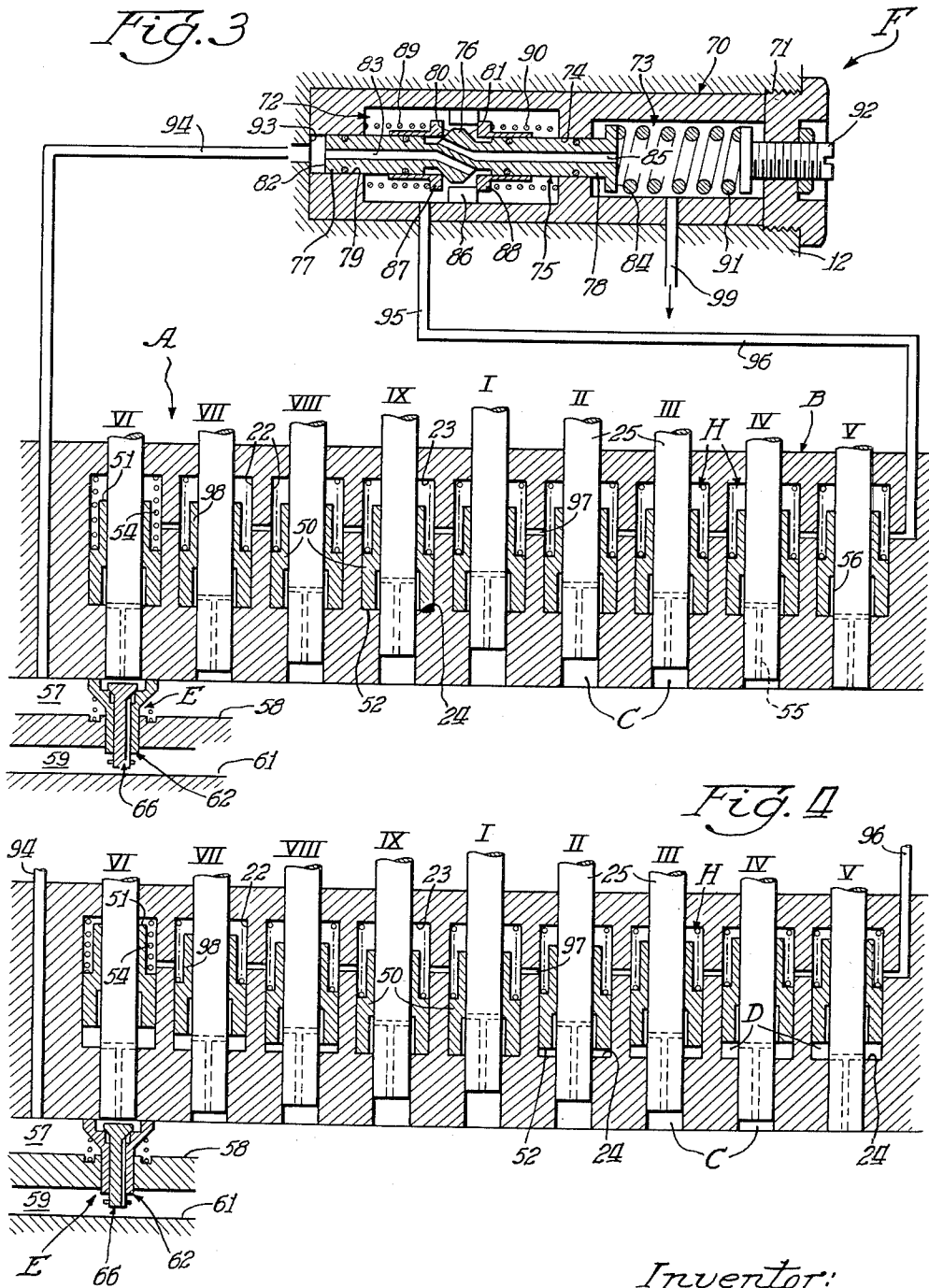
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3 Sheets-Sheet 2



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VARIABLE DISPLACEMENT HYDRAULIC APPARATUS

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This invention relates to a variable displacement hydraulic apparatus, and, in particular, relates to a variable displacement piston type pump or motor having a plurality of means respectively operatively associated with the pistons for selectively varying the displacement of the pistons and thus the displacement of the hydraulic apparatus.

It is well known in the art to provide a piston type pump or motor with means to vary the displacement thereof. Generally, each piston type pump or motor comprises a housing having a cavity formed therein and a cylinder block disposed within the cavity, the cylinder block having a plurality of circularly arranged cylinders formed therein and adapted to receive respectively a plurality of pistons operatively interconnected with means to permit reciprocative movement thereof. When the hydraulic apparatus is utilized as a hydraulic pump, each piston is sequentially reciprocated relative to the cylinder block and is adapted to draw fluid into the respective cylinder from an inlet formed in the housing during the movement thereof from its top dead center position to its bottom dead center position, the movement of the piston being referred to as its intake or suction stroke. Upon movement of the respective piston from its bottom dead center position back toward its top dead center position, the movement of the piston being referred to as its discharge stroke, the respective piston displaces the fluid, which had been drawn into the respective cylinder, out through an outlet formed in the housing, the outlet being restricted in the normal manner whereby the fluid displaced to the outlet is pressurized. When the hydraulic apparatus is being utilized as a hydraulic motor, each piston is moved from its top dead center position to its bottom dead center position by pressure fluid entering the respective cylinder from the inlet, the movement of the respective piston being referred to as its intake or power stroke. Upon movement of the respective piston from its bottom dead center position back toward its top dead center position, the movement of the piston being referred to as its discharge stroke, the respective piston displaces the fluid, which has been forced into the respective cylinder, out through the outlet. Therefore, the amount of fluid displaced by the hydraulic apparatus when acting as a pump or motor depends upon the volumetric increase of the cylinders during the movement of the pistons from their top dead center positions to their bottom dead center positions.

In order to vary the displacement of the hydraulic apparatus of the previously described type when the speed of the reciprocation of the pistons remains constant, some means must be provided to vary the effective intake and discharge strokes of each piston to thereby vary the amount of fluid displaced thereby from the inlet to the outlet. One such means has been to provide selectively movable valve means adapted to vary the length of time that the inlet is fluidly interconnected with the cylinders during the intake strokes of the pistons. Another such means has been to vary the actual distance of movement of the pistons between their top dead center positions and their bottom dead center positions and thereby vary the amount of fluid displaced by each piston. However, in these prior known devices, it has been found that rather

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complicated and expensive mechanism must be utilized to vary the effective strokes of the pistons.

It is, therefore, an object of this invention to provide a hydraulic apparatus having improved means to vary the displacement thereof.

Another object of this invention is to provide a piston type hydraulic apparatus having improved means to vary the effective strokes of each piston thereof without varying the actual reciprocative movement of each piston in order to vary the displacement of the apparatus.

A further object of this invention is to provide a hydraulic apparatus comprising, a cylinder block having a plurality of cylinders, a plurality of pistons disposed respectively defined in part by the pistons, means for sequentially reciprocating the pistons between their bottom dead center positions and their top dead center positions, an inlet and an outlet leading respectively to and from the cavities, valve means adapted to interconnect the inlet with each cavity when the respective piston is moved from top dead center to bottom dead center to thereby permit the cavity to receive fluid from the inlet and being adapted to interconnect the outlet with each cavity when the respective piston is moved from bottom dead center to top dead center whereby each piston is adapted to displace the fluid from the respective cavity to the outlet, a plurality of chambers respectively interconnected with the cavities, the chambers respectively being defined in part by a plurality of movable members whereby movement of the members from a first position to a second position relative to the block increases the volume of the respective chambers, and means operatively interconnected with the members adapted to move each member to its first position when the respective piston is moved to bottom dead center, the means being adapted to permit selected movement of each member from its first position to a selected position as the respective piston moves from bottom dead center to top dead center, whereby at least a portion of the fluid displaced by each piston is delivered to its respective chamber rather than to the outlet to thus vary the displacement of the apparatus.

Other and more particular objects, advantages, and uses of this invention will become apparent from a reading of the following specification taken in connection with the accompanying drawings forming a part thereof and wherein:

FIGURE 1 illustrates, in an axial cross-sectional view, one embodiment of a hydraulic apparatus formed in accordance with the teachings of this invention and is taken on line 1—1 of FIGURE 2.

FIGURE 2 illustrates, in an axial cross-sectional view, the hydraulic apparatus illustrated in FIGURE 1 and is taken on line 2—2 thereof.

FIGURE 3 illustrates, in a schematic view, the hydraulic apparatus illustrated in FIGURE 1, the apparatus operating under maximum displacement conditions.

FIGURE 4 illustrates, in a schematic view, the hydraulic apparatus illustrated in FIGURE 1, the apparatus operating under partial displacement conditions.

FIGURE 5 illustrates, in an axial cross-sectional view, another embodiment of a hydraulic apparatus formed in accordance with the teachings of this invention and is taken on line 5—5 of FIGURE 6.

FIGURE 6 illustrates, in an axial cross-sectional view, the hydraulic apparatus illustrated in FIGURE 5 and is taken on line 6—6 thereof.

FIGURE 7 illustrates, in a schematic view, the hydraulic apparatus illustrated in FIGURE 5, the apparatus operating under maximum displacement conditions.

FIGURE 8 illustrates, in a schematic view, the hy-

draulic apparatus illustrated in FIGURE 5, the apparatus operating under partial displacement conditions.

Reference is now made to the accompanying drawings wherein like reference numerals and letters are used throughout the various figures thereof to indicate like parts where appropriate, and particular reference is made to FIGURE 1 illustrating a hydraulic apparatus, generally indicated by the reference letter A, formed in accordance with the teachings of this invention and includes a housing 10 comprising a plurality of housing sections 11 and 12 suitably secured together in aligned relation in any feasible manner.

The housing section 11 has a flat end wall 13 interrupted by a bore 14 which terminates within the housing section 11 and defines an end wall 15. The flat surface 13 of the housing section 11 is adapted to sealably abut a flat surface 16 formed on the housing section 12 when the housing sections 11 and 12 are secured together in aligned relation.

A cylinder block, generally indicated by the reference letter B, is disposed within the bore 14 of the housing 10 and comprises a plurality of sections 17 and 18 sealably secured together in any feasible manner. The cylinder block B has a pair of opposed flat surfaces 19 and 20, the flat surface 20 sealably engaging the flat surface 16 of the housing section 12. A plurality of circularly arranged, parallel bores or cylinders 21 are formed in the cylinder block B and respectively interrupt the flat surfaces 19 and 20 thereof. In the embodiment illustrated in FIGURES 1 and 2, the cylinder block B is formed with nine cylinders 21, however, it is to be understood that any number of cylinders may be provided. A plurality of annular grooves 22 are formed in the cylinder block B and are respectively disposed coaxially with the cylinders 21. Each annular groove 22 defines end walls 23 and 24 within the cylinder block B.

A plurality of pistons 25 are disposed respectively in the cylinders 21. Each piston 25 has a substantially flat end 26 adapted to cooperate with the respective cylinder 21 and the housing section 12 to define a cylinder or piston cavity C. Each piston 25 has an enlarged end 27 formed with a socket 28 adapted to receive a hemispherical portion 29 of a bearing slipper 30. The bearing slipper 30 is disposed in engagement with a rotatable cam or swash plate 31 disposed within the housing bore 14. The cam plate 31 is adapted to engage a plurality of hemispherically shaped slippers 32 carried respectively within a plurality of sockets 33 formed in a plate 34, the plate 34 being suitably secured to the end wall 15 of the housing 10. The cam plate 31 has a pair of opposed shafts 35 and 36 projecting therefrom, the shaft 35 extending through a bore formed in the housing section 11 and being rotatably supported therein by suitable bearing means 37. The shaft 35 has a splined end portion 38 adapted to be interconnected with a suitable power source (not shown) or a utilization device (not shown).

The shaft 36, extending from the cam plate 31, is received within a bore 39 formed in a member 40 rotatably carried by the cylinder block B. The member 40 has a cylindrical projection 41 received within a bore 42 formed centrally through the cylinder block B. The remaining portion of the member 40 is received within a larger counter bore 43 formed in the cylinder block B, the bore 43 defining an end wall 44 at the juncture thereof with the smaller bore 42. The member 40 is rotatably supported within the bore 43 by suitable bearing means 45 and is provided with a substantially hemispherically shaped end portion 46 which is adapted to engage a substantially hemispherically shaped socket 47 formed in a rocker arm or member 48. The rocker arm or member 48 has a plurality of bores 49 formed therethrough which respectively receive the pistons 25. In this manner, as is well known in the art, the rocker arm or member 48 maintains the bearing slippers 30 carried by the pistons 25 in sealing contact with the cam plate 31 in order to

provide sequential reciprocative movement thereof relative to the cylinder block B.

When each piston 25 is at its top dead center position, i.e., when the movement of the piston 25 to the right, as viewed in FIGURE 1, is terminated by the relative position of the cam plate 31 and further movement of the cam plate will cause the piston 25 to begin to move to the left, the respective cavity C defined in part by the end surface 26 of the piston 25 is at its smallest volume, and upon movement of the piston 25 to the left from its top dead center position, the end surface 26 thereof causes the volume of the respective cavity C to increase. The maximum volume of the cavity C is reached when the respective piston 25 is at its bottom dead center position, i.e., when the movement of the piston 25 to the left is terminated and further movement of the cam plate 31 will cause the piston 25 to begin to move back toward top dead center.

A plurality of movable members 50 are disposed respectively in the annular grooves 22. Each member 50 has a pair of opposed end surfaces 51 and 52 interrupted by a bore 53 passing centrally therethrough, the bore 53 permitting the respective member 50 to be telescopically disposed about the respective piston 25 and be movable relative thereto. A plurality of small compression springs 54 are disposed respectively within the annular grooves 22, each spring 54 having one end thereof engaging the end wall 23 of the respective annular groove 22 and the other end thereof engaging the respective member 50 whereby the forces of the compression springs 54 tend to maintain the end surfaces 52 of the members 50 in engagement with the end walls 24 of the annular grooves 22.

Upon movement of each member 50 to the left, as viewed in FIGURE 1, relative to the cylinder block B in opposition to the force of the respective compression spring 54, the end surface 52 thereof cooperates with the annular groove 22, piston 25, and end wall 24 to define a chamber D. The chamber D has a minimum volume when the end surface 52 of the respective member 50 is disposed in engagement with the end wall 24 of the respective annular groove 22 and a maximum volume when further movement thereof to the left, as viewed in FIGURE 1, is prevented by the end wall 23 of the respective annular groove 22. Each chamber D is fluidly interconnected with its associated piston cavity C by a passage 55 formed in the respective piston 25, the passage 55 interrupting the respective end surface 26 thereof and fluidly interconnecting opposed sides of the piston 25 with an annular groove 56 formed in the member 50. The annular groove 56 is, in turn, fluidly interconnected with the end surface 52 of the member 50 and is thus fluidly interconnected with the respective chamber D. As shown in FIGURE 4, when one of the members 50 is moved a predetermined distance relative to its respective piston 25, the passage 55 formed in the respective piston 25 is directly interconnected with the chamber D.

The flat surface 16 of the housing section 12 is interrupted by an annular groove 57, the annular groove 57 being disposed adjacent to and in fluid communication with the cylinders 21 when the housing sections 11 and 12 are secured together in aligned relation. The annular groove 57 is also fluidly interconnected with an outlet 58 formed in the housing 10. A second annular groove 59 is formed in the housing section 12 and is disposed coaxially with and spaced from the annular groove 57 and is fluidly interconnected therewith by a plurality of passages 60 respectively disposed in substantially coaxial relation with the cylinders 21. The annular groove 59 is, in turn, fluidly interconnected with an inlet 61 formed in the housing 10.

A plurality of valve means E are carried by the housing section 12 adjacent the cylinders 21 and each comprises a first valve member 62 having an enlarged head portion 63 adapted to sealably engage the end surface 20 of the cylinder block B and thus close off fluid communication

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between a responsive cavity C and the outlet annular groove 57. The valve member 62 is normally biased to its closed position by a small compression spring 64 interposed between the housing section 12 and the valve member 62. Each valve member 62 has a small cylindrical projection 65 sealably received in one of the bores 60 and is axially movable relative thereto. A second valve member 66 is carried by each valve member 62 and has an enlarged head 67 adapted to close off fluid communication between the respective cavity C and the inlet annular groove 59 when seated against the valve member 62, the second valve member 66 having a cylindrical projection 68 loosely received within a bore 69 formed through the valve member 62 and fluidly interconnecting the respective cavity C with the inlet annular groove 59.

In this manner, when the piston 25, illustrated in the lower portion of FIGURE 1, is being reciprocated to the left, the piston cavity C thereof increases in volume and the resulting vacuum condition causes the valve member 66 to move from sealing engagement with the valve member 62 whereby fluid is permitted to flow from the inlet 61 through the bore 69 of the valve member 62 and thus into the cavity C. When the piston 25 is moving to the right as illustrated in the upper portion of FIGURE 1, the force of the fluid trapped within the cavity C acts against the head 67 of the valve member 66 and forces the head 67 thereof into sealing engagement with the valve member 62 and thus closes off communication between the cavity C and the inlet annular groove 59. As the piston 25 moves further to the right, the force of the fluid within the cavity C acts against the valve head 63 of the first valve member 62 in opposition to the force of the compression spring 64 and moves the valve 62 out of sealing engagement with the flat surface 20 of the cylinder block B in order to fluidly interconnect the cavity C with the outlet annular groove 57 whereby the fluid in the cavity C is forced out to the outlet 58.

A control valve, indicated generally by the reference letter F, is carried by the housing 10 and includes a valve housing 70 received within a bore 71 formed in the housing section 12. The valve housing 70 is provided with a pair of spaced chambers 72 and 73 interconnected by a bore 74. An axially movable valve member 75, having an enlarged medial portion 76 and a pair of opposed coaxial shafts 77 and 78 extending therefrom, is disposed within the valve housing 70, the shaft 77 being sealably received within a bore 79 formed in the valve housing 70 and interconnected with the chamber 72 and the shaft 78 being sealably received within the bore 74 interconnecting the chambers 72 and 73.

The enlarged portion 76 of the valve member 75 is provided with a pair of opposed bevelled surfaces 80 and 81. The bevelled surface 81 is fluidly interconnected with an end 82 of the shaft 77 by a passage 83 formed in the valve member 75, and similarly, the bevelled surface 80 is fluidly interconnected with an end 84 of the shaft 78 by a passage 85 formed in the valve member 75.

A small projection 86 is carried by the valve housing 10 and is disposed within the chamber 72, the projection 86 being adapted to be engaged by a pair of sleeve valve members 87 and 88 respectively, telescopically disposed about the shafts 77 and 78 of the valve member 75. The sleeve valve 87 is normally biased against the bevelled surface 80 of the valve member 75 by a compression spring 89 disposed between the valve housing 70 and the sleeve valve 87. Similarly, the sleeve valve 88 is normally biased into sealing engagement with the bevelled surface 81 of the valve member 75 by a compression spring 90 interposed between the valve housing 70 and the sleeve valve 88.

When the sleeve valves 87 and 88 are in sealing engagement with respective bevelled surfaces 80 and 81 of the valve member 75, the sleeve valves 87 and 88 respectively prevent fluid communication between the passages 83 and 85 and the chamber 72. When the enlarged

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portion 76 of the valve member 75 is centered relative to the projection 86, the sleeve valves 87 and 88 are both permitted to sealably engage the enlarged portion 76 thereof and thereby prevent fluid communication between the chamber 72 and the passages 83 and 85. However, upon movement of the valve member 75 from its centered position relative to the projection 86, one of the sleeve valves 87 or 88 will engage the projection 86 and be prevented from following further movement of the valve member 75 and thereby permit fluid communication between one of the passages 83 and 85 and the chamber 72.

The valve member 75 is normally biased to the left, as viewed in FIGURE 1, by a compression spring 91 interposed between the end 84 of the valve member 75 and a selectively adjustable member 92 carried by the valve housing 70, the adjustable member 92 being adapted to vary the force of the compression spring 91 tending to move the valve member to the left upon adjusting the position of the member 92 relative to the valve housing 70. Movement of the valve member 75 to the left is limited because the end 82 of the valve member 75 is adapted to abut an end wall 93 formed in the valve housing 70.

When the valve member 75 is biased by the spring 91 against the end wall 93 of the valve housing 70, the sleeve valve 81 is disengaged from the bevelled surface 81 of the valve member 75 by the projection 86 and the sleeve valve 87 is in sealing engagement with the bevelled surface 80 of the valve member 75 whereby only the passage 83 is fluidly interconnected with the chamber 72.

The bore 79 formed in the valve housing 70 is fluidly interconnected with the outlet annular groove 57 by a passage 94 whereby a portion of the fluid delivered to the outlet 58 by the apparatus A is directed to the valve F. The force of the fluid conveyed to the bore 79 acts against the end 82 of the valve member 75 and thus tends to move the valve member 75 to the right in opposition to the force of the compression spring 91.

The chamber 72 of the valve F is fluidly interconnected with the annular grooves 22 formed in the cylinder block B in the following manner. A passage 95 formed in the housing section 12 fluidly interconnects the chamber 72 of the valve F with a passage 96 formed in the member 40 carried by the cylinder block B. The passage 96 in the member 40 is, in turn, fluidly interconnected with an annular space 97 formed between the sections 17 and 18 of the cylinder block B, the space 97 being, in turn, fluidly interconnected with the annular grooves 22 at a point between the end wall 23 thereof and the movable member 50 regardless of the positions of the movable members 50 relative to the cylinder block B as the movable members 50 are provided with reduced portions 98 at the ends 51 thereof.

The chamber 73 of the valve F is fluidly interconnected with a chamber G defined between the end wall 15 and the cylinder block B in the housing bore 14 by passage means 99 leading from the chamber 73 of the valve F through the housing section 12 and the cylinder block B to the bore 14. The chamber G is, in turn, fluidly interconnected with the exterior of the housing 10 by a drain port 100.

The operation of the hydraulic apparatus A, when acting as a hydraulic pump, will now be described. During the initial starting phases of the hydraulic apparatus A, the force of the compression springs 54 maintain the movable members 50 in their extreme right positions whereby the end surfaces 52 thereof are disposed in engagement with the end wall 24 and the volumes of the chambers D, defined thereby, are at minimum values. Upon rotation of the shaft 38 by a suitable power source (not shown), the cam plate 31 is rotated thereby causing reciprocation of the pistons 25 in a manner well known in the art. As each piston 25 moves from top dead center to bottom dead center, the volume of the respective

piston cavity C increases from its minimum volume to its maximum volume and thus causes fluid to be drawn from the inlet 61 into the respective cavity C through the valve means E in a manner previously described. When the respective piston 25 begins its discharge stroke, i.e., moves from bottom dead center toward top dead center, the fluid within the respective cavity C is displaced by the piston 25 out the outlet 58 through the valve means E in the manner previously described. A portion of the pressure fluid displaced to the outlet 58 is conveyed by the passage 94 to the valve F. Since the pump A is beginning its operation, the spring 91 has forced the valve member 75 to its extreme left position thereby permitting the portion of the pressure fluid directed by the passage means 94 to pass through the opened passage 83 into the chamber 72, and thus from the chamber 72 through the passage means 95-97 into the annular grooves 22 between the end walls 23 and the movable members 50.

During the initial operation of the apparatus A, the pressure value of the fluid delivered to the outlet 58 is relatively small until a sufficient quantity has been delivered. Therefore, the force of the springs 54 is sufficient to overcome the force of the fluid in the piston cavities C tending to cause movement of the members 50 away from the end walls 24 during the starting operation. As the pressure value of the pressure fluid in the cavities C increases, the pressure value of the fluid conveyed to the annular grooves 22 increases correspondingly and thereby maintains the members 50 against the end walls 24.

When the pressure value of the pressure fluid delivered to the outlet 58 reaches the desired predetermined value, as determined by the particular compression force setting of the compression spring 91, the force of the pressure fluid conveyed by the passage 94 to the valve F acts against the end 82 of the valve member 75 and causes movement thereof to the right in opposition to the force of the compression spring 91 until the enlarged portion 76 thereof is centered relative to the projection 86. As previously stated, when the portion 76 of the valve member 75 is centered relative to the projection 86, the valve sleeves 87 and 88 are permitted to seal off communication between the passages 85 and 83 in the valve member 75 and the chamber 72 of the valve F. As long as the pressure value of the pressure fluid within the outlet 58 remains at the predetermined pressure value, the valve member 75 remains centered within the valve housing 70 and the valve sleeves 87 and 88 close off the respective passages 85 and 83 thereby maintaining a predetermined volume or static head of fluid within a reservoir H, the reservoir H comprising the annular grooves 22, passage means 95-97, and the chamber 72 of the valve F. The predetermined amount of volume of fluid within the reservoir H maintains the movable members 50 in their extreme right position in opposition to the force of the pressure fluid within the piston cavities C which tends to flow into the respective chambers D during the compression strokes of the respective pistons 25 and cause movement of the members 50 to the left. Since the fluid within the reservoir H is noncompressible and is prevented from escaping through the closed passage 85, the members 50 remain in their extreme right positions.

As shown schematically in FIGURE 3, each piston 25 is numbered I-IX in the same manner that the pistons 25 are numbered in FIGURE 2. As shown in FIGURE 3, the hydraulic apparatus A is operating at its full displacement condition, i.e., the entire amount of fluid received into each piston cavity C during the intake stroke of the respective piston 25 is displaced to the outlet 58. The piston I is at bottom dead center and is about to begin its discharge stroke. The pistons II-V are in various stages of their discharge strokes, the piston V nearing top dead center. The pistons VI-IX are in various stages of their intake strokes and thus draw the entire amount

of fluid received within their respective cavities C from the inlet 61. Therefore, it can be seen that the total amount of fluid displaced by each piston 25 from the inlet 61 to the outlet 58 under full displacement conditions is the amount represented by the volume of the cavity C of the piston I.

When the pressure value of the pressure fluid in the outlet 58 exceeds the predetermined pressure value, the force thereof acting against the end 82 of the valve member 75 causes the valve member 75 to move to the right past its center position in opposition to the biasing means 91 and thus permits the valve sleeve 87 to become unseated from the enlarged portion 76 thereof by engaging the projection 86. When the valve sleeve 87 is unseated it can be seen that the passage 85 of the valve member 75 is now fluidly interconnected with the reservoir H and thus interconnects the reservoir H with the bore 14 in the housing 10 by means of the chamber 73 and passage 99. Since the force of the hydraulic fluid within each piston cavity C during the discharge stroke of the respective piston 25 is acting against the end 52 of the respective member 50 tending to move the same to the left and thus increase the volume of the respective chamber D, this force is not resisted by a static head of fluid within the reservoir H and thus causes the piston 50 to move to the left and displace a portion of the volume of fluid within the reservoir H out through the valve means F to the drain 100. Since the members 50 are permitted to move to the left during the discharge strokes of the respective pistons 25, it can be seen that a portion of the fluid within each piston cavity C is permitted to flow from the cavity C into the respective chamber D rather than to the outlet 58 as the respective piston moves from bottom dead center to top dead center. If the chamber D has a volume equal to the volume of the respective cavity C when the respective piston is at bottom dead center, the entire amount of fluid displaced from the piston cavity C by the respective piston 25 is delivered to the chamber D and none is delivered to the outlet 58 resulting in zero displacement of the hydraulic apparatus A.

As soon as the pressure value of the pressure fluid within the outlet 58 drops to the desired predetermined pressure value, the compression spring 91 returns the valve member 75 to its centered position thereby closing off communication between the reservoir H and the drain 100. However, since a portion of the fluid from the predetermined amount required to maintain the members 50 in their extreme right positions has been displaced from the reservoir H, the new volume of fluid contained within the reservoir H permits the members 50 to move relative to the housing 10 and thus reduce the displacement of the hydraulic apparatus from its full displacement condition in the following manner.

Since there is a reduced volume of fluid now contained within the reservoir H, as illustrated in FIGURE 4, the piston I is at bottom dead center and its respective member 50 is maintained in a position providing the minimum volume for the respective chamber D. However, as the pistons II-V move through their respective discharge strokes, the pressure value of the fluid within the respective piston cavity C acts against the respective members 50 and causes the same to move away from the end walls 24 of the annular grooves 22 and thus increase the volume of the respective chambers D. This movement of the members 50 increases the volume of the chambers D as the respective pistons 25 move from bottom dead center to top dead center and thus permits a portion of the fluid being acted upon by the pistons 25 to be displaced from the cavities C to the chambers D rather than to the outlet 58. As the cam plate 31 causes each piston 25 to pass through top dead center, i.e., changes the movement of the respective piston 25 from its discharge stroke to its intake stroke, the respective member 50 thereof is moved by the new volume or static head of fluid within the reservoir H in order to decrease the volume of the

respective chamber D. As shown in FIGURE 4, when each piston 25 begins its intake stroke, the respective member 50 moves toward the end wall 24 of the respective annular groove 22 and thus causes the fluid received within the respective chamber D during the discharge stroke to be communicated back to the respective piston cavity C during at least a part of the intake stroke of the piston 25. Since the fluid from the chamber D is being drawn into the piston cavity C by the action of the respective member 50 together with the suction condition created by the movement of the piston 25, the inlet valve 66 remains closed. When the entire amount of fluid has been displaced from the chamber D back to the respective piston cavity C by the respective member 50 as the piston 25 moves from top dead center toward bottom dead center (see piston IX, FIGURE 4), further movement of the piston 25 toward bottom dead center causes the inlet valve 66 to open to thereby permit fluid to be drawn into the cavity C from the inlet 61 in the manner previously described. Therefore, the amount of fluid that is drawn into the piston cavities C from the inlet 61, during this partial displacement condition, is equal to the amount of fluid that is permitted to be delivered to the outlet 58.

Should the pressure value of the pressure fluid within the outlet 58 fall below the desired predetermined pressure value when the apparatus A is operating under partial displacement conditions, the compression spring 91 will move the valve member 75 to the left past its centered position and thereby permit the valve sleeve 88 to be unseated and permit the pressure fluid from the outlet 58 to flow through the passage means 94 into the reservoir H and increase the volume of the fluid in the reservoir H acting against the movable members 50. By increasing the volume of fluid within the reservoir H, the amount of movement of the members 50 is decreased and thus the amount of fluid delivered to the outlet 58 increases. Therefore, the control valve F tends to maintain the pressure value of the pressure fluid delivered by the apparatus A to the outlet 58 at a predetermined pressure value by varying the displacement of the apparatus A.

The predetermined pressure value setting of the apparatus A can be selectively changed by changing the compression force of the spring 91, i.e., by adjusting the position of the member 92 relative to the housing 70.

It is to be understood that the operation of the hydraulic apparatus A, when acting as a hydraulic motor, is substantially the same as that set forth above except that pressurized fluid is delivered to the apparatus A in order to cause reciprocation of the pistons 25 and thus rotation of a utilization means coupled to the drive shaft 35.

It should further be understood that other means could be provided for regulating the amount of fluid to be contained within the reservoir H than the control valve means F previously described.

The hydraulic apparatus A', illustrated in FIGURE 5, is substantially the same as the hydraulic apparatus A illustrated in FIGURE 1 except that the positions of the means for varying the displacement of the apparatus A' have been changed. In FIGURE 5, the cylinder block B' is provided with a plurality of cylinders 21' having a plurality of pistons 25' disposed respectively therein. Each piston 25' is provided with a bore 101 fluidly interconnected with the end 26' thereof by a passage 102. A movable member 103 is sealably disposed within each bore 101 and is normally biased against an end wall 104 of the bore 101 by a compression spring 105 disposed between another end wall 106 of the bore 101 and the movable member 103. Each movable member 103 cooperates with the bore 101 and end wall 104 to define a chamber D', the chambers D' being utilized for the same purpose as the chambers D previously described.

The passage 96', formed in the member 40' and leading from the control valve F', is interconnected to the

space in the bores 101 between the movable members 103 and the end wall 106 by an annular passage 107 formed in the cylinder block B'. The annular passage 107 is, in turn, interconnected with each bore 101 by a passage 108 formed in each piston 25'. The bores 101, passages 96', 107 and 108, together with the control valve F' define a reservoir H' similar to the reservoir H previously described.

The operation of the hydraulic apparatus A' illustrated in FIGURE 5 is substantially the same as that set forth for the apparatus A illustrated in FIGURE 1 and, therefore, the particular details of the operation will not be described.

As shown in FIGURE 7, the hydraulic apparatus A' is operating under full displacement conditions, i.e., the movable members 103 are disposed and maintained against the ends 104 of the respective pistons 25' by the static head of fluid within the reservoir H' whereby the volume of each chamber D is at a minimum volume thus permitting the entire flow of fluid from the inlet 61' to pass to the outlet 58'.

The pistons 25', illustrated schematically in FIGURE 7, are numbers I'-IX' in the same manner as shown in FIGURE 6. Piston I' is at bottom dead center and further movement of the cam plate 31' will cause piston I' to begin its discharge stroke. Pistons II'-V' are in various stages of their discharge strokes, piston V' nearing top dead center. Since the members 103 are maintained against the end walls 104 during the entire discharge strokes of the pistons 25', the entire amount of fluid drawn into the piston cavities C' during the intake strokes is delivered to the outlet 58'. Pistons VI'-IX' are in various stages of their intake strokes drawing the entire amount of fluid into the cavities C' from the inlet 61'.

As shown in FIGURE 8, the hydraulic apparatus A' is operating under partial displacement conditions, i.e., the members 103 are permitted to move relative to the pistons 25' as the amount of the static head of pressure fluid in the reservoir H' has been decreased from the predetermined amount necessary to maintain the members 103 in engagement with the ends 103 of the pistons 25'. Thus a portion of the fluid displaced by the pistons 25' during their discharge strokes is communicated from the respective piston cavity C' into the chambers D'. The fluid conveyed to the chambers D' during the discharge strokes of the respective pistons is displaced by the movable members 103 back into the respective cavities C' during the intake strokes of the pistons 25'. Thus the amount of fluid received from the inlet 61' into the piston cavities C' during the intake strokes of the pistons 25' is only the same amount that is actually delivered to the outlet 58'.

As shown schematically in FIGURE 8, piston I' is at bottom dead center and, upon further rotation of the cam plate 31', the piston I' will move toward top dead center. Pistons II'-V' are in various stages of their discharge strokes. As each piston 25' moves from bottom dead center toward top dead center, the respective member 103 moves away from the respective end wall 104 increasing the volume of the respective chamber D' whereby a portion of the fluid within the respective cavity C' is forced into the expanding chamber D' rather than to the outlet 58'. Movement of the members 103 is permitted because the amount of fluid in the reservoir H' has been reduced from the amount necessary to provide maximum displacement of the apparatus A'. If, when each piston 25' reaches top dead center, the volume of the chamber D' equals the volume of the piston cavity C' when the piston was at bottom dead center, the displacement of the apparatus A' will be zero. Pistons VI'-IX' are in various stages of their intake strokes. As each piston 25' moves from top dead center to bottom dead center, the respective member 103 is forced toward the end wall 104 forcing the fluid within the

chamber D' back to the piston cavity C'. The members 103 are moved toward the end wall 104 because the static head of fluid in the reservoir H' is simultaneously being displaced by another member 103 moving away from the respective end wall 104. Since the fluid within the chambers D' is being expelled therefrom into the respective cavities C' during at least a portion of the intake strokes of the respective pistons, the only fluid drawn into the cavities C' from the inlet 61' is that amount which was actually displaced to the outlet 53'.

Therefore, it can be seen that there has been described an improved hydraulic apparatus having means whereby the displacement thereof is selectively varied without varying the actual movement of the pistons between bottom dead center and top dead center.

While this invention has been disclosed in connection with certain specific embodiments thereof, it is to be understood that this is by way of example rather than limitation, and it is intended that the invention be defined by the appended claims.

What is claimed is:

1. In a hydraulic apparatus, a block; means defining a cylinder in said block; a piston disposed in said cylinder; means providing a cavity defined in part by said piston; means for reciprocating said piston between bottom dead center and top dead center relative to said block whereby movement of said piston from top dead center to bottom dead center increases the volume of said cavity; means defining a chamber fluidly interconnected with said cavity, said chamber being defined in part by a movable member carried by said piston whereby movement of said member from a first position to a second position relative to said block increases the volume of said chamber; means providing a fluid reservoir defined in part by said member; and means for selectively applying and venting fluid respectively to and from said reservoir whereby when said reservoir is filled with a predetermined amount of fluid, said member is maintained in said first position, and when the predetermined amount of fluid in said reservoir is decreased a selected amount, said member is permitted to move from its said first position to a selected position as said piston moves from bottom dead center to top dead center to thereby vary the combined volume of said cavity and said chamber when said piston is at top dead center.

2. In a hydraulic apparatus, a cylinder block; means defining a plurality of cylinders in said block; a plurality of pistons disposed respectively in said cylinders; means providing a plurality of cavities respectively defined in part by said pistons; means for sequentially reciprocating said pistons between bottom dead center and top dead center whereby movement of each piston from top dead center to bottom dead center increases the volume of the respective cavity; a plurality of members carried respectively by said pistons and movable relative thereto; means defining a plurality of chambers respectively interconnected with said cavities, each chamber being defined in part by the respective member whereby movement of said members from a first position to a second position relative to said block increases the volume of the respective chambers; and means operatively interconnected with said members adapted to move each member to its said first position when the respective piston is moved to bottom dead center, said means being adapted to permit selected movement of each member from its said first position to any position between its said first and second positions as its respective piston moves from bottom dead center to top dead center to thereby vary the combined volume of each cavity and its respective chamber when the respective piston is at top dead center.

3. In a hydraulic apparatus, a cylinder block; means defining a plurality of cylinders in said block; a plurality of pistons disposed respectively in said cylinders; means providing a plurality of cavities respectively defined in

part by said pistons; means for sequentially reciprocating said pistons between bottom dead center and top dead center whereby movement of each piston from top dead center to bottom dead center increases the volume of the respective cavity; means defining a plurality of chambers in said block, said chambers being respectively interconnected with said cavities and being respectively defined in part by a plurality of movable members carried respectively by said pistons whereby movement of said members from a first position to a second position relative to said block increases the volume of the respective chambers; and means operatively interconnected with said members adapted to move each member to its said first position when the respective piston is moved to bottom dead center, said means being adapted to permit selected movement of each member from its said first position to any position between its said first and second positions as its respective piston moves from bottom dead center to top dead center to thereby vary the combined volume of each cavity and its respective chamber when the respective piston is at top dead center.

4. In a hydraulic apparatus, a cylinder block; means defining a plurality of cylinders in said block; a plurality of pistons disposed respectively in said cylinders; means providing a plurality of cavities respectively defined in part by said pistons; means for sequentially reciprocating said pistons between bottom dead center and top dead center whereby movement of each piston from top dead center to bottom dead center increases the volume of the respective cavity; means defining a plurality of chambers respectively disposed in said pistons and respectively interconnected with said cavities, said chambers being respectively defined in part by a plurality of movable members whereby movement of said members from a first position to a second position relative to said block increases the volume of the respective chambers; and means operatively interconnected with said members adapted to move each member to its said first position when the respective piston is moved to bottom dead center, said means being adapted to permit selected movement of each member from its said first position to any position between its said first and second positions as its respective piston moves from bottom dead center to top dead center to thereby vary the combined volume of each cavity and its respective chamber when the respective piston is at top dead center.

5. In a hydraulic apparatus, a block; means defining a cylinder in said block; a piston disposed in said cylinder; means providing a cavity defined in part by said piston; means for reciprocating said piston between bottom dead center and top dead center; means defining an inlet and an outlet leading respectively to and from said cavity; valve means being adapted to interconnect said inlet with said cavity when said piston is moved from top dead center to bottom dead center to thereby permit said cavity to receive fluid from said inlet and being adapted to interconnect said outlet with said cavity when said piston is moved from bottom dead center to top dead center whereby said piston is adapted to displace said fluid from said cavity to said outlet; means defining a chamber fluidly interconnected with said cavity, said chamber being defined in part by a movable member carried by said piston whereby movement of said member from a first position to a second position relative to said block increases the volume of said chamber; means providing a fluid reservoir defined in part by said member; and means for selectively applying and venting fluid respectively to and from said reservoir whereby when said reservoir is filled with a predetermined amount of fluid, said member is maintained in said first position, and when the predetermined amount of fluid in said reservoir is decreased a selected amount, said member is permitted to move from its said first position to a selected position as said piston moves from bottom dead center to top dead center whereby at least a portion of the fluid dis-

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placed by said piston from said cavity is delivered to said chamber rather than to said outlet to thus vary the displacement of said apparatus.

6. In a hydraulic apparatus, a cylinder block; means defining a plurality of cylinders in said block; a plurality of pistons disposed respectively in said cylinders; means providing a plurality of cavities respectively defined in part by said pistons; means for sequentially reciprocating said pistons between bottom dead center and top dead center; means defining an inlet and an outlet leading respectively to and from said cavities; valve means being adapted to interconnect said inlet with each cavity when the respective piston is moved from top dead center to bottom dead center to thereby permit the cavity to receive fluid from said inlet and being adapted to interconnect said outlet with each cavity when the respective piston is moved from bottom dead center to top dead center whereby each piston is adapted to displace the fluid from the respective cavity to said outlet; a plurality of members carried respectively by said pistons and movable relative thereto; means defining a plurality of chambers respectively interconnected with said cavities, each chamber being defined in part by the respective member whereby movement of said members from a first position to a second position relative to said block increases the volume of the respective chambers; and means operatively interconnected with said members adapted to move each member to its said first position when the respective piston is moved to bottom dead center, said means being adapted to permit selected movement of each member from its said first position to any position between its said first and second positions as its respective piston moves from bottom dead center to top dead center whereby at least a portion of the fluid displaced by each piston is delivered to the respective chamber rather than to said outlet to thus vary the displacement of the apparatus.

7. In a hydraulic apparatus, a cylinder block; means defining a plurality of cylinders in said block; a plurality of pistons disposed respectively in said cylinders; means providing a plurality of cavities respectively defined in part by said pistons; means for sequentially reciprocating said pistons between bottom dead center and top dead center; means defining an inlet and an outlet leading respectively to and from said cavities; valve means being adapted to interconnect said inlet with each cavity when the respective piston is moved from top dead center to bottom dead center to thereby permit the cavity to receive fluid from said inlet and being adapted to interconnect said outlet with each cavity when the respective piston is moved from bottom dead center to top dead center whereby each piston is adapted to displace the fluid from the respective cavity to said outlet; means defining a plurality of chambers respectively disposed in said pistons and respectively interconnected with said cavities, said chambers being respectively defined in part

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by a plurality of movable members whereby movement of said members from a first position to a second position relative to said block increases the volume of the respective chambers; and means operatively interconnected with said members adapted to move each member to its said first position when the respective piston is moved to bottom dead center, said means being adapted to permit selected movement of each member from its said first position to any position between its said first and second positions as its respective piston moves from bottom dead center to top dead center whereby at least a portion of the fluid displaced by each piston is delivered to its respective chamber rather than to said outlet to thus vary the displacement of the apparatus.

8. In a hydraulic apparatus, a cylinder block; means defining a plurality of cylinders in said block; a plurality of pistons disposed respectively in said cylinders; means providing a plurality of cavities respectively defined in part by said pistons; means for sequentially reciprocating said pistons between bottom dead center and top dead center; means defining an inlet and an outlet leading respectively to and from said cavities; valve means being adapted to interconnect said inlet with each cavity when the respective piston is moved from top dead center to bottom dead center to thereby permit the cavity to receive fluid from said inlet and being adapted to interconnect said outlet with each cavity when the respective piston is moved from bottom dead center to top dead center whereby each piston is adapted to displace the fluid from the respective cavity to said outlet; means defining a plurality of chambers in said block, said chambers being respectively interconnected with said cavities and being respectively defined in part by a plurality of movable members carried respectively by said pistons whereby movement of said members from a first position to a second position relative to said block increases the volume of the respective chambers; and means operatively interconnected with said members adapted to move each member to its said first position when the respective piston is moved to bottom dead center, said means being adapted to permit selected movement of each member from its said first position to any position between its said first and second positions as its respective piston moves from bottom dead center to top dead center whereby at least a portion of the fluid displaced by each piston is delivered to its respective chamber rather than to said outlet to thus vary the displacement of the apparatus.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,016,837

January 16, 1962

Gerald S. Dlugos

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 2, lines 13 and 14, after "respectively" insert -- in the cylinders, a plurality of cavities respectively --; column 4, lines 43 and 44, for "responptive" read -- respective --.

Signed and sealed this 15th day of May 1962.

(SEAL)

Attest:

ERNEST W. SWIDER

Attesting Officer

DAVID L. LADD

Commissioner of Patents