May 21, 1968 L. C. JENNINGS ET AL 3,384,027

HYDRAULIC STARTING SYSTEM AND VALVES THEREFOR

Filed Aug. 3, 1966 3 Sheets-Sheet 1

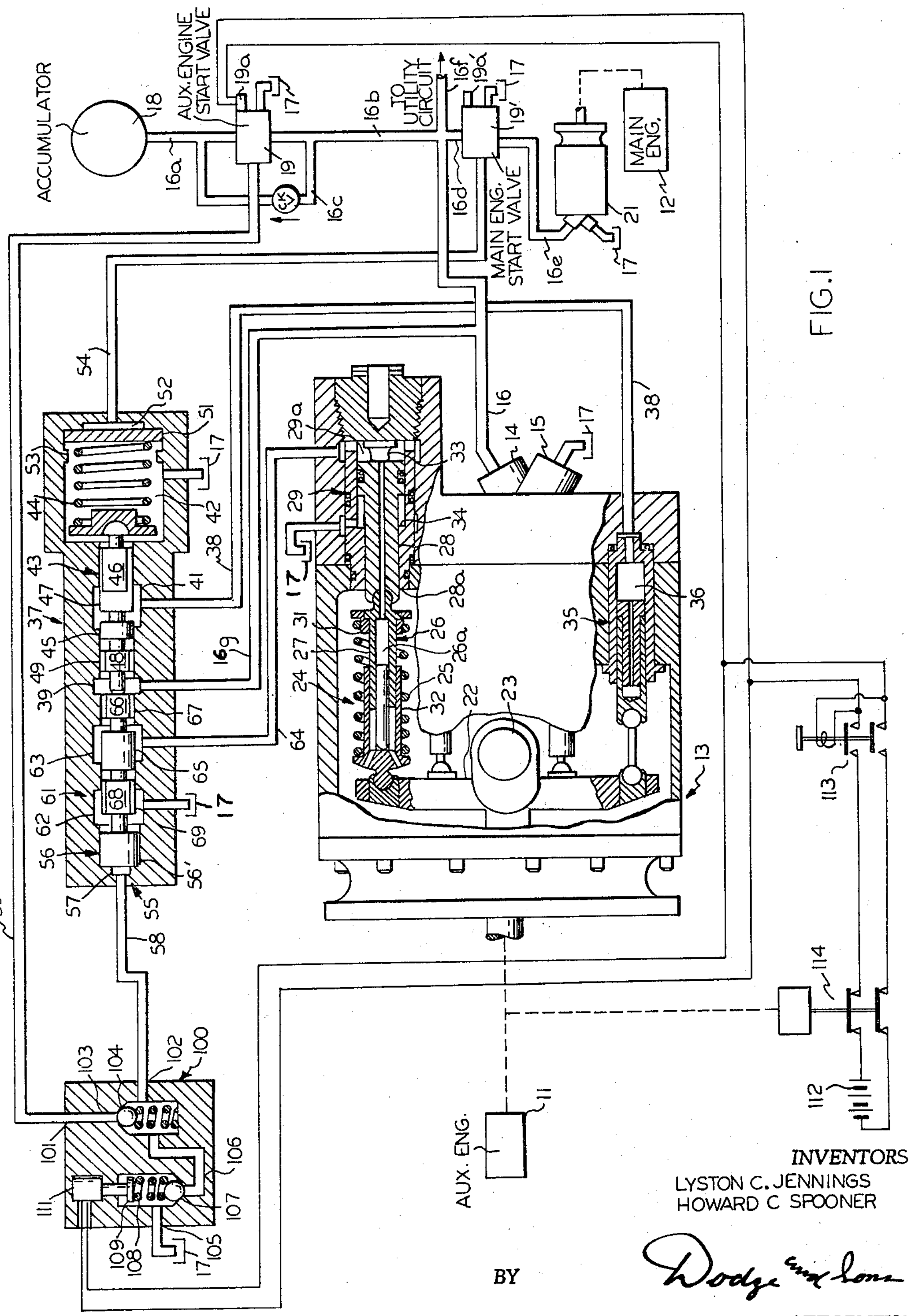

FIG. 1

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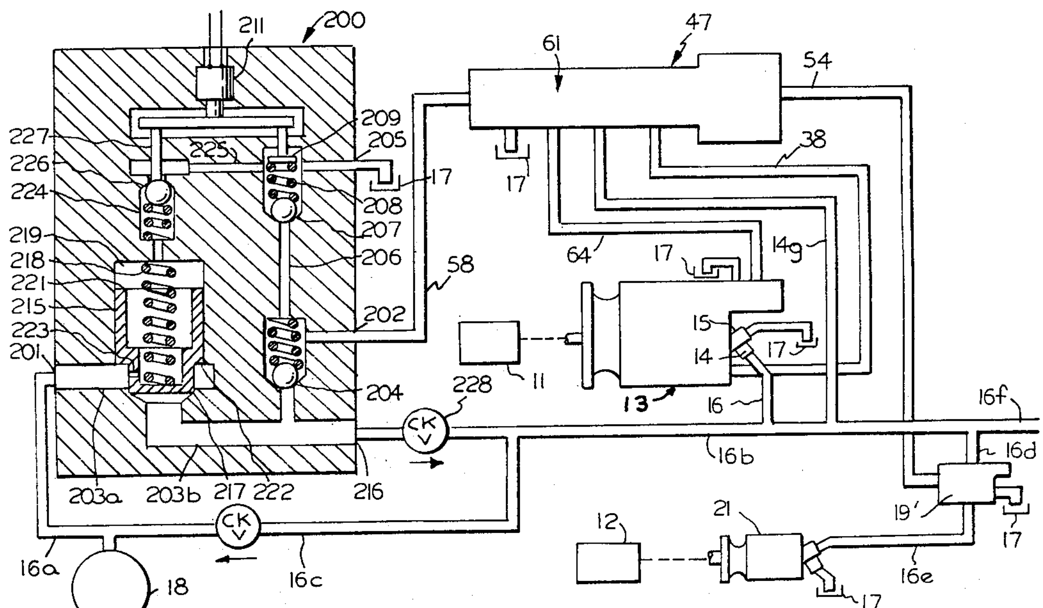

FIG.2

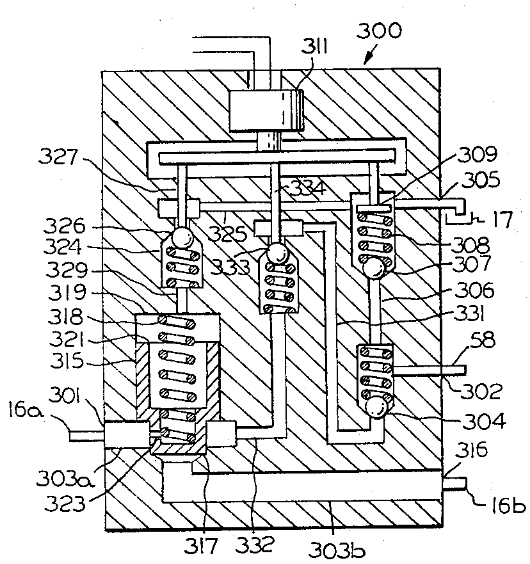

FIG.3

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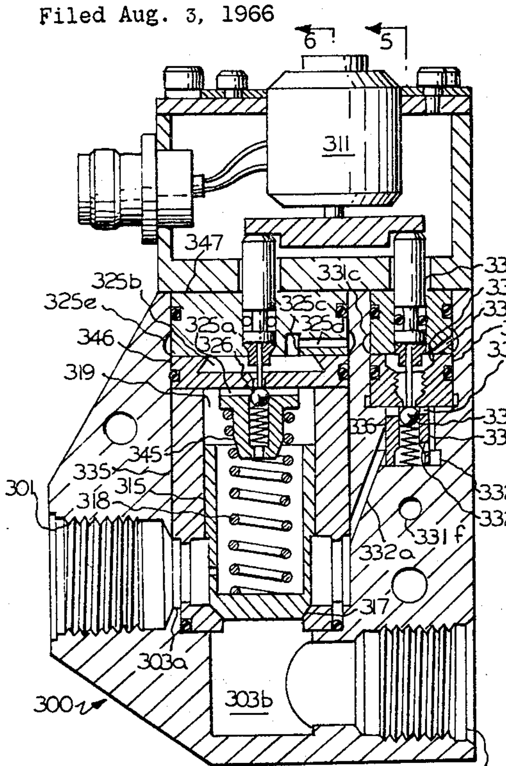

FIG.4

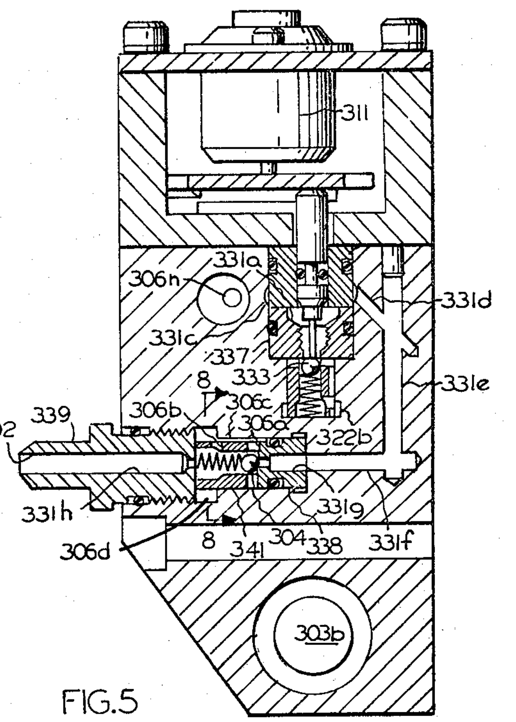

FIG.5

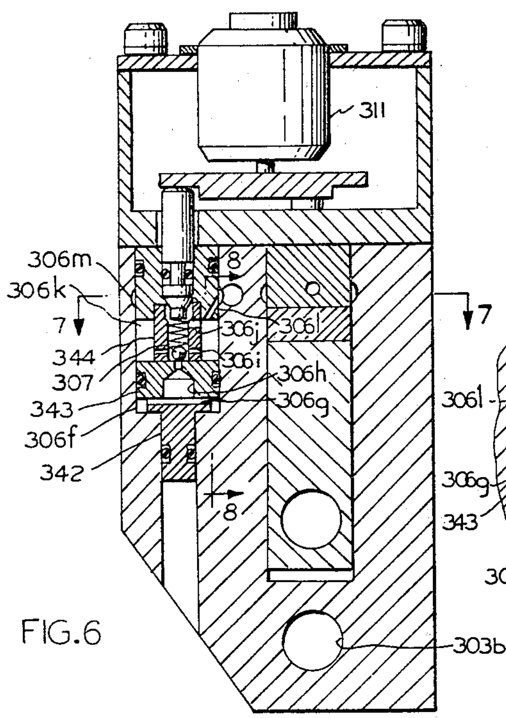

FIG.6

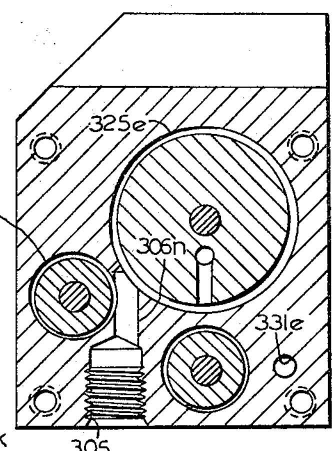

FIG.7

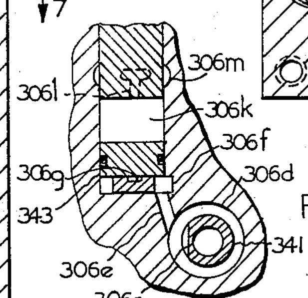

FIG.8

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3,384,027
HYDRAULIC STARTING SYSTEM AND VALVES THEREFOR

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Filed Aug. 3, 1966, Ser. No. 569,921
8 Claims. (Cl. 103—162)

This invention relates to hydraulic starting and pumping systems.

U.S. Patents 3,203,165, granted Aug. 31, 1965, and 3,234,889, granted Feb. 16, 1966, disclose systems of this kind which employ overcenter motor-pump units and which use an accumulator as the source of motive fluid for the starting operation. In each of these systems, the positioning mechanism for the displacement control element of the motor-pump unit includes a fluid pressure control motor, a pressure responsive control valve having supply and exhaust positions in which it connects the control motor with the high pressure side of the system and the reservoir, respectively, and an actuating motor which is controlled by the engine start valve and which acts on the control valve in aid of its normal pressure reaction surface. During the starting cycle, the start valve connects the actuating motor with the high pressure side of the system for the purpose of holding the control valve in its supply position. On the other hand, during the pumping operation, the start valve vents the actuating motor and thereby allows the control valve to perform its normal supply and exhaust functions.

Experience with these prior systems indicates that if the start valve is maintained open, and consequently the actuating motor is maintained in communication with the high pressure side of the system, after either the accumulator is depleted of oil or the engine becomes self-sustaining, the displacement control element of the motor-pump unit will oscillate rapidly between large displacement positions at opposite sides of the zero displacement position. The reason for this is that each of the events just mentioned causes a sudden, drastic reduction in the pressure in the high pressure side of the system which makes it impossible for the actuating motor to hold the control valve in its supply position. As a result, the control valve shifts to its vent position, the pressure in the control motor is suddenly dissipated, and the positioning mechanism rapidly moves the displacement control element over center. At this time, the motor-pump unit commences to discharge fluid to the high pressure side of the system and to raise its pressure. When the pressure is restored to the level required to enable the actuating motor to reposition the control valve in its supply position, the control motor is suddenly subjected to the full pressure then existing in the high pressure side of the system. Therefore, this motor rapidly shifts the displacement control element back to the other side of the zero displacement position and again reverses the direction of flow through the motor-pump unit. In cases where the engine is running, oscillation of the displacement control element continues until the start valve is closed and the control mechanism is set to hold the displacement control element at the proper side of the zero displacement position for pumping operation. On the other hand, in the case of abortive starts, wherein the engine does not attain a self-sustaining speed, the oscillation continues until the torque load imposed by the motor-pump unit brings engine to rest. In either case, the oscillations produce pressure pulsations of large magnitude throughout the entire system which create excessive stresses in, and can even cause failure of, the various hydraulic components.

The object of this invention is to provide an improved starter system in which the severity of these oscillations of the displacement control element is greatly reduced. According to this invention, the system includes valving means for maintaining the actuating motor under the initial pressure of the accumulator from the commencement of the starting cycle until the start valve is closed. This improvement insures that the control valve will be maintained in its supply position regardless of the pressure in the high pressure side of the system, and thus absolutely prevents this valve from suddenly changing the pressure in the control motor. Now, the control motor always responds directly to the pressure in the high pressure side of the system during the starting cycle and does not produce the violent oscillations of the control element which have been encountered in the prior systems.

In the preferred embodiment of the invention, the valving means which insures proper operation of the actuating motor is incorporated in a package which also includes the engine start valve and a common actuator for the two valve units. This package may also incorporate means for insuring that the positioning mechanism for the displacement control element is set for motoring operation before the motor-pump unit commences to develop torque. This feature precludes the undesirable momentary reverse rotation of the engine at the instant the start cycle is initiated which can be encountered with the prior systems. The packaged arrangement of the start valve and the valve means which controls the actuating motor is a desirable feature because it is less expensive than the alternative of providing separate valves, and, in addition, it permits the invention to be incorporated in existing systems in a routine manner by regular maintenance-personnel.

The preferred and several alternative embodiments of the invention are described herein in detail with reference to the accompanying drawings in which:

FIG. 1 is a schematic diagram showing a hydraulic starting and pumping system of the type disclosed in U.S. Patent 3,234,889 and incorporating one form of the present invention.

FIG. 2 is a schematic diagram of a similar starting and pumping system incorporating a second form of the invention.

FIG. 3 is a schematic diagram of the preferred valve package.

FIG. 4 is a sectional view of the actual preferred embodiment.

FIGS. 5 and 6 are sectional views taken on lines **5—5** and **6—6** of FIG. 4.

FIG. 7 is a sectional view taken on line **7—7** of FIG. 6 and

FIG. 8 is a sectional view taken on lines **8—8** of FIG. 5 and lines **8—8** of FIG. 6.

The starting and pumping system shown in FIG. 1 is employed to start auxiliary and main turbine engines **11** and **12** and to provide hydraulic fluid under pressure to a utility circuit (not shown). The system includes an overcenter motor-pump unit **13** which is connected to drive and be driven by auxiliary engine **11**, and which is provided with high and low pressure ports **14** and **15** that are connected, respectively, with main conduit **16** and reservoir **17**. Motive fluid for driving unit **13** as a motor is supplied by a gas-charged accumulator **18** through a circuit including conduits **16*a***, **16*b*** and **16** and controlled by the auxiliary engine start valve **19**. When unit **13** is being driven as a pump, it draws fluid from reservoir **17** and discharges it under pressure into conduit **16**. This pressurized fluid may then flow to, and thus recharge, accumulator **18** through conduits **16*b***, **16*c*** and **16*a***, or pass through conduit **16*d***, main start valve **19′** and conduit **16*e*** to hydraulic starter **21**, and thus be used as the motive fluid for starting main engine **12**, or pass through conduit **16*f*** to the utility circuit.

The start valves **19** and **19'** are of the pilot-operated type disclosed in U.S. Patent 3,203,165, and each has a main valve which is spring biased to a closed position. When the pilot valve of either of the valves **19** and **19'** is shifted from its venting to its pressurizing position by the association solenoid **19*a*** or **19*a'***, the connection between the piloted motor and reservoir **17** is interrupted, and this motor is connected with the conduit upstream of the start valve, that is, conduit **16*a*** in the case of valve **19**, and conduit **16*d*** in the case of valve **19'**. As a result, the piloted motor shifts the main valve to open position. Venting of either piloted motor allows the spring to close the main valve.

The displacement of and direction of flow through unit **13** is controlled by cam plate **22** which is movable in opposite directions from the illustrated neutral or zero displacement position about the axis of trunnion **23**. Cam plate **22** is biased in the counterclockwise direction by a spring-motor assembly **24** including the coil compression spring **25** and a fluid pressure piston motor **26**. The cylinder **27** of motor **26** is connected to the piston **28** of a shifting motor **29** and carries a spring seat having a longitudinal extension **31** which is arranged to abut the end of cylinder **32** when the two cylinders move toward each other. This extension **31** defines a limit stop for cam plate **22** which, during the pumping operation, prevents the cam plate from moving over center, i.e., through the neutral position. The piston **28** is designed to move between the illustrated position, in which it abuts stop **33**, and a second position, in which its head abuts shoulder **34**, for positioning assembly **24** for motoring and pumping operatitons, respectively.

Cam plate **22** is moved in the clockwise direction about the axis of trunnion **23** against the opposing bias of assembly **24** by a fluid pressure control motor **35**. Fluid is supplied to and exhausted from the working chamber **36** of this motor through a pressure responsive control valve **37** with which it is connected by conduit **38**. Control valve **37** includes an inlet chamber **39** which is connected with the main conduit **16** through conduit **16*g***, an outlet chamber **41** which communicates with conduit **38**, an exhaust chamber **42** which is connected with reservoir **17**, and a sliding valve spool **43**. This valve spool has supply and exhaust positions and an intermediate lap position, and is biased to the illustrated exhaust position by a coil compression spring **44**. In this position, land **45** isolates outlet chamber **41** from inlet chamber **39**, and a flat **46** on land **47** provides a flow path which connects outlet chamber **41** with exhaust chamber **42**. The fluid pressure in chamber **39** acts upon the left end of spool **43** and serves to shift this member to the right, first to a lap position in which lands **45** and **47** isolate chamber **41** from the other two chambers, and then to the supply position wherein land **47** continues to block communication between chambers **41** and **42**, and the flat **48** extending across land **49** connects outlet chamber **41** with inlet chamber **39**.

The pressure in inlet chamber **39** required to hold valve spool **43** in the lap position against the opposition of spring **44** is termed the reference pressure, and valve **47** includes two devices for changing this pressure. The first, which raises the reference pressure, comprises a movable spring seat **51** for spring **44**, and a piston motor which includes the right side of seat **51** and a working chamber **52**. When working chamber **52** is vented, seat **51** assumes the illustrated low spring-load position, and, when the working chamber is pressurized, the seat is moved to the left to a high spring-load position defined by stop **53**. A conduit **54** connects working chamber **52** with the pilot valve portion of main engine start valve **19'**, so that this chamber is vented and pressurized whenever the start valve **19'** is closed and opened, respectively. The second device for changing the reference pressure acts to lower it from the normal value, and it comprises a piston motor **55** including the piston **56** which abuts the left end of spool **43**, and a working chamber **57**. The working chamber **57** is connected with the pilot valve portion of auxiliary engine start valve **19** through a pair of conduits **58** and **59** and the valving device **100** provided by the present invention. As will appear below, this chamber **57** is continuously subjected to the initial pressure in accumulator **18** whenever valve **19** is open and, at all other times, it is vented to reservoir **17**.

The piston **56** of motor **55** also serves as the valve spool of a selector valve **61** which simultaneously vents and pressurizes the working chambers **26*a*** and **29*a*** of motors **26** and **29**. This valve comprises the inlet chamber **39** of control valve **47**, an exhaust chamber **62** which is in continuous communication with reservoir **17**, and an outlet chamber **63** which is connected with working chamber **29*a*** through conduit **64**. An axial passage **28*a*** in piston **28** interconnects working chambers **26*a*** and **29*a***. During pumping operation, selector valve **61** assumes the illustrated position wherein land **65** blocks communication between chambers **62** and **63**, and the flat **66** extending across land **67** interconnects chambers **63** and **39**. During the starting operation, valve **61** shifts to the right to a position in which land **65** blocks communication between chambers **63** and **39**, and the flat **68** extending across land **69** connects outlet chamber **63** with exhaust chamber **62**. Thus, selector valve **61** vents and pressurizes the motors **26** and **29** during the pumping and motoring operations, respectively. Since the diameter of the end land **56'** of piston **56** is greater than the diameter of lands **65** and **67**, piston **56** will always shift to the right when the pressures in working chamber **57** and inlet chamber **39** are equal.

The valving device **100** provided by the present invention includes a pair of ports **101** and **102** which are connected, respectively, with conduits **59** and **58**, and which are interconnected by passage **103** containing spring biased check valve **104**. Check valve **104** is oriented to permit flow from conduit **59** to conduit **58**, but to block flow in the reverse direction. Valving unit **100** also includes an exhaust port **105** which is in continuous communication with reservoir **17** and which is connected with port **102** by a passage **106** containing a second spring biased check valve **107**. The biasing spring **108** of this check valve has a movable seat **109** which is carried by the armature of a solenoid **111** so that the closing bias acting on the check valve changes as the solenoid is energized and de-energized. Solenoid **111** is connected in parallel with the solenoid **19*a*** of auxiliary engine start valve **19** in an energization circuit which includes battery **112** and which is controlled by the manually operated start switch **113** and a speed controlled switch **114** that responds to the speed of engine **11**.

Operation

Since U.S. Patent 3,234,889 contains a complete description of the operation of the system shown in FIG. 1, and the improvements provided by the present invention affect only the motoring mode of operation, the following description of operation will treat only the starting cycle of engine **11**.

Before commencement of the starting cycle, accumulator **18** is precharged with gas at a pressure of 1500 p.s.i. and is then charged with oil by a hand pump circuit (not shown). It is assumed that the fully charged pressure of the accumulator is 3000 p.s.i., and that the three reference pressures of control valve **37** are 1500 p.s.i., 3000 p.s.i. and 4000 p.s.i.

In order to start auxiliary engine **11** the operator closes switch **113** to energize solenoid **19*a*** and open start valve **19**. This permits fluid from the accumulator **18** to flow into the high pressure port **14** of the motor-pump unit through conduits **16*a***, **16*b*** and **16**, and also permits fluid at accumulator pressure to pass to the working chamber

57 of motor 55 through the pilot portion of valve 19, conduit 59, port 101, passage 103, check valve 104, port 102 and conduit 58. Since solenoid 111 is energized simultaneously with solenoid 19*a*, the load in spring 108 is now sufficient to keep check valve 107 closed and prevent bleed off of the pressure in working chamber 57. The pressure of 3000 p.s.i. in this chamber causes motor 55 to shift selector valve 61 to a position in which it vents motors 26 and 29, and to shift control valve 37 to its supply position in which control motor 35 is connected with main conduit 16. As a result, control motor 35 moves cam plate 22 in the clockwise direction to its maximum displacement position at the motoring side of neutral and maintains it in that position against the opposing bias of spring 25.

The fluid delivered to motor-pump unit 13 causes it to develop torque and accelerate engine 11. As the engine accelerates, the pressure of the fluid delivered by accumulator 18 progressively decreases from its initial value of 3000 p.s.i. However, this change in pressure is not reflected in working chamber 57 because the check valve 104 closes as soon as the pressure in conduit 59 begins to drop below the initial charge pressure of the accumulator. Therefore, as long as solenoid 111 is maintained energized and check valve 107 is held closed, the pressure in working chamber 57 remains at 3000 p.s.i. and valves 37 and 61 remain in their supply and vent positions, respectively. Because of this, the pressure in working chamber 36 of control motor 35 will be substantially the same as the pressure in main conduit 16 throughout the starting cycle.

Under normal conditions, engine 11 will have been ignited and will have achieved self-sustaining operation before accumulator pressure decreases to 1500 p.s.i. and the accumulator is depleted of oil. Since control motor 35 is dimensioned to hold cam plate 22 in the maximum displacement position as long as the pressure in its working chamber 36 is above 1500 p.s.i. it follows that the cam plate 22 in the normal case will not move away from its maximum displacement position during the starting cycle. When the engine reaches a self-sustaining speed, switch 114 automatically opens the holding circuit for switch 113 and allows this switch in turn to open and de-energize solenoids 19*a* and 111. De-energization of solenoid 19*a* allows auxiliary engine start valve 19 to close and interrupt the flow of fluid from the accumulator 18 to high pressure port 14. On the other hand, de-energization of solenoid 111 reduces the load in spring 108 and permits check valve 107 to open under the action of pressurized oil trapped in working chamber 57. Therefore, this oil may now escape to reservoir 17 through conduit 58, port 102, passage 106 and port 105. Since engine 11 is now driving motor-pump unit 13 as pump, and cam plate 22 is still at the motoring side of the neutral position, unit 13 will commence to evacuate main conduit 16. As a result, the pressure in this conduit and in the working chamber 36 of control motor 35 will decrease well below 1500 p.s.i., and spring 25 will move cam plate 22 in the counterclockwise direction to a small displacement position at the pumping side of the neutral position. At the same time, spring 44 will return valves 36 and 61 to their illustrated vent and supply positions, respectively. As soon as cam plate 22 moves over center, unit 13 commences to discharge oil under pressure to conduit 16 and thus quickly restores its pressure to 1500 p.s.i. As this is happening, selector valve 61 transmits system pressure to shifting motor 29 and causes it to move the spring-motor assembly 24 to its pumping position wherein the stop defined by extension 31 is effective to prevent the cam plate 22 from moving back to the motoring side of neutral. Cam plate 22 will now assume a position in which the displacement of unit 13 is equal to the rate of leakage from the system. At this time the pressure in inlet chamber 39 of valve 37 will move spool 43 to its lap position.

In the abnormal case, where accumulator 18 is given an inadequate gas precharge or is charged with an insufficient quantity of oil for a start cycle, the engine 11 does not achieve a self-sustaining speed by the time accumulator 18 is depleted of oil. When this happens, the engine 11, which has considerable momentum, will commence to coast and drive unit 13 as a pump. Since cam plate 22 is at the motoring side of neutral position, unit 13 will draw fluid from conduit 16 and discharge it to reservoir 17. This pumping action will quickly decrease the pressure in conduit 16 toward zero. In the prior system of Patent 3,234,889, wherein conduit 58 is in constant, direct communication with conduit 59, this change in pressure causes valves 37 and 61 to shift to their exhaust and supply postiions, respectively. This action resulted in sudden venting of working chamber 36, and in sudden pressurization of working chambers 26*a* and 29*a*, and caused the controls for cam plate 22 to move it rapidly to a large, and perhaps even the maximum, displacement position at the pumping side of neutral. Unit 13 would then commence to discharge oil to conduit 16 and recharge accumulator 18. As soon as the pressure in conduit 16 was restored to 1500 p.s.i., valves 37 and 61 would shift back to their supply and vent positions, respectively, and suddenly apply full system pressure to working chamber 36 and vent working chambers 26*a* and 29*a*. Now the controls would shift cam plate 22 rapidly back to a rather large displacement position at the motoring side of neutral. At this point, unit 13 would again commence to act as a motor and drive engine 11. However, as soon as accumulator 18 was again depleted of oil, the controls would produce another violent oscillation of cam plate 22. These oscillations continued until the engine 11 came to rest, and, since they were accompanied by severe pressure pulsations in the conduits connected with ports 14 and 15, there was ample opportunity for the system components to be damaged.

In contrast to this, the valving device 100 provided by the present invention holds the initial charge pressure of accumulator 18 in working chamber 57, and thus enables motor 55 to keep valves 37 and 61 in their supply and exhaust positions, respectively, as long as solenoid 111 remains energized. Therefore, in this system the pressure changes in conduit 16 always are reflected directly in working chamber 36, and cannot cause valve 61 to pressurize motors 26 and 29. With this arrangement, motor 35 and spring 25 still move the cam plate 22 back and forth across the neutral position during an abortive start, but the rate of movement of the claim plate and the amplitude of its oscillation are much less than in the prior system. Actual experience with this improvement shows that it reduces to tolerable levels the pressure pulsations encountered during abortive starts.

Another abnormal case in which the invention effects an improvement concerns starts in which the switch 114 fails to open when the engine 11 reaches a self-sustaining speed. This situation produces the same effect as an abortive start, except that the unit 13 operates continuously as a pump which discharges alternately through ports 14 and 15, and, since the engine is running under its own power, the oscillations of cam plate 22 continue until start switch 113 is opened manually. As in the case of the abortive start, the valving device 100 so reduces the severity of these oscillations that the pressure pulsations are kept within tolerable limits.

The FIGURE 2 embodiment

The system shown in FIG. 2 is generally the same as the one of FIG. 1, except that here the valves 204 and 207, which correspond to check valves 104 and 107 embodied in the device 100 of FIG. 1, are combined with the auxiliary engine start valve in a single package 200.

In this case, the passage which interconnects ports **201** and **202** has two enlarged sections **203a** and **203b**, which are separated by the main poppet **215** of the start valve, and the latter section leads to a delivery port **216** as well as to check valve **204**. The elements **201**, **203a**, **203b** and **216** define the supply path through which motive fluid is delivered to the motor-pump **13**. The main poppet **215** is urged toward its seat **217** by a coil compression spring **218** and by the fluid pressure in a pilot chamber **219** which acts upon its upper surface **221**. The poppet is shifted in the opening direction against this bias by the pressure in passage section **203a** which acts upon the annular shoulder **222**. Pilot chamber **219** is connected with inlet port **201** by passage section **203a** and a restricted passage **223** formed in the poppet, and is connected with exhaust port **205** through a path comprising passages **224** and **225** and controlled by a pilot valve in the form of spring biased check valve **226**. This check valve is oriented to normally block flow from pilot chamber **219**, but is opened by push rod **227** whenever solenoid **211** is energized to hold valve **207** closed.

The valving package **200** is incorporated in the system by connecting ports **202** and **205** with conduit **58** and reservoir **17**, respectively, by connecting port **201** directly with accumulator **18** through conduit **16a**, and by connecting port **216** with the conduits **16b** and **16** leading to the high pressure port **14** of motor-pump unit **13**. This last mentioned connection includes a check valve **228** which permits flow from, but not into, passage section **203b**. When the FIG. 2 system is in a standby condition, solenoid **211** is de-energized and valves **204**, **207** and **226** assume their illustrated positions. Although the fluid in passage section **203a** is subjected to the full charge pressure of accumulator **18**, and thus tends to open main poppet **215**, the fluid in pilot chamber **219** is under the same pressure and acts on a larger reaction surface, namely upper surface **221**. Therefore, the net pressure force acting on the poppet **215** supplements the biasing force developed by spring **218** and holds poppet **215** tightly against its seat **217**. This precludes leakage from accumulator **18**.

In order to start engine **11**, the start switch (not shown) is closed to energize solenoid **211** and cause it to close and open the valves **207** and **226**, respectively. Opening of valve **226** allows oil to escape from pilot chamber **219** to reservoir **17** at a rate greater than that at which it can enter this chamber through restricted passage **223**. As a result, the pressure in chamber **219** decreases below that in passage section **203a**, and the net pressure force acting on poppet **215** shifts this member to open position against the opposition of spring **218**. Fluid under accumulator pressure now is delivered to the high pressure port **14** of unit **13** via passage section **203b**, port **216**, and conduits **16b** and **16**, and to the working chamber **57** of actuating motor **55** through passage section **203b**, check valve **204**, port **202** and conduit **58**. The FIG. 2 system now effects starting of engine **11** in the same way as the FIG. 1 system.

During a normal starting cycle, solenoid **211** is de-energized as soon as engine **11** becomes self-sustaining. Therefore, at this time, valves **207** and **226** are allowed to open and close, respectively. As soon as valve **226** closes, the pressures in chamber **219** and passage section **203a** equalize, and main poppet **215** closes. Simultaneously, opening of valve **207** automatically sets the controls for unit **13** to their pumping condition. Therefore, this unit can now recharge the accumulator **18** and perform its other pumping functions. In the case of an abortive start or a failure of switch **114**, the valving device **200** serves to prevent violent oscillations of the cam plate of unit **13** in the same way as its counterpart in FIG. 1. While the cyclic variations in the pressure in conduit **16b** during these conditions are reflected in passage section **203a**, and may cause closing and opening movement of main poppet **215**, this will not adversely affect the performance of the motor-pump unit **13** or the starting system.

The preferred embodiment

The preferred valving device **300**, which is illustrated schematically in FIG. 3, is similar to device **200** in that it incorporates the start valve and the check valves necessary to trap fluid in actuator motor **55**. However, in this embodiment, the path between the pilot chamber **319** of the start valve and exhaust port **305** includes a flow restrictor **329**, and the inlet and outlet ports **301** and **302** are interconnected by a path which comprises passages **331** and **332** and which is controlled by check valve **333** rather than main poppet **315**. The check valve **333** normally blocks flow from port **301** to port **302**, but is mechanically unseated to permit such flow by an actuating rod **334** which is operated by solenoid **311**. Thus, when the solenoid is energized to effect opening of pilot valve **326** and closure of the vent valve **307**, it simultaneously opens valve **333** and permits fluid under accumulator pressure to flow to the actuating motor **55** through a path comprising port **301**, passages **332** and **331**, valve **304**, outlet port **302** and conduit **58**.

It will be observed that, since spring **25** in motor-pump unit **13** biases cam plate **22** to a position at the pumping side of neutral when the starting system is at rest, unit **13** will momentarily rotate engine **11** in the reverse direction at the commencement of the starting cycle if it commences to develop torque before the controls have been energized to move the cam plate over center. The preferred embodiment eliminates this condition. This is accomplished by so sizing flow restrictor **329** that, when valves **326** and **333** are first opened, fluid under accumulator pressure is transmitted to outlet port **302** before the pressure in pilot chamber **319** can decrease sufficiently to permit opening of main poppet **315**. As a result of this delay, actuating motor **55** will have time to shift valves **37** and **61** to the positions required for motoring operation before high pressure port **14** is subjected to full accumulator pressure. Since shifting of these valves vents motors **26** and **29** and places motor **35** in direct communication with conduit **16**, and since the pressure required by motor **35** to shift the cam plate over center is much less than the pressure required by unit **13** to satisfy the breakaway torque requirement of engine **11**, it should be apparent that, when main poppet **315** opens and the pressure in conduit **16** rises, motor **35** will move the cam plate to the motoring side of neutral before the unit **13** commences to rotate. Thus, the valving device **300** precludes any reverse rotation of engine **11**.

It should be noted that since outlet port **302** in the FIG. 3 embodiment is isolated from the high pressure conduit **16b** when solenoid **311** is de-energized, systems incorporating this form of the invention do not require the check valve **228** used in FIG. 2.

The details of the actual valving device **300** are shown in FIGS. 4–8, wherein the counterparts of the components shown in FIG. 3 are, as far as possible, identified by the same reference numerals. While the construction of this embodiment will be apparent from an inspection of these figures, it will be helpful to describe specifically the following flow paths shown schematically in FIG. 3:

(1) The path connecting inlet port **301** with check valve **333** is shown in FIG. 4 and comprises annular groove **303a** formed in the outer periphery of sleeve **335**, drilled housing passage **332a**, annular housing chamber **322b**, longitudinal passage **332c** defined by a flat on the outer periphery of sleeve **336**, and radial passages **332d** and **332e**.

(2) The path connecting check valve **333** with port **302** is shown in FIGS. 4 and 5 and comprises axial passage **331a** formed in block **337**, drilled passage **331b**, annular housing groove **331c**, drilled housing passages **331d**, **331e** and **331f**, axial passage **331g** formed in the seat sleeve **338**, check valve **304**, and the axial passage **331h** formed in fitting **339**.

(3) The path connecting outlet port **302** with exhaust port **305** is shown in FIGS. 5–8 and comprises axial passage **331*h***, radial passages **306*a*** and **306*b***, longitudinal passage **306*c*** defined by a flat on the outer periphery of sleeve **341** (see FIG. 5), annular housing chamber **306*d***, drilled housing passage **306*e***, housing chamber **306*f*** (see FIGS. 6 and 8), slot **306*g*** formed in plug **342**, axial passage **306*h*** in seat block **343**, check valve **307**, radial passages **306*i*** and **306*j*** formed in sleeve **344**, chamber **306*k***, drilled passage **306*l***, annular housing chamber **306*m***, and drilled housing passage **306*n*** (see FIG. 7).

(4) The path connecting pilot chamber **319** with exhaust port **305** is shown in FIGS. 4 and 7 and comprises slot **325*a*** formed in spring seat **345**, check valve **326**, chamber **325*b*** formed in insert **346**, drilled passages **325*c*** and **325*d*** formed in block **347**, annular housing chamber **325*e***, and drilled housing passage **306*n***. In this embodiment, either passage **325*a*** or passage **325*d*** may serve as the flow restrictor **329** of FIG. 3.

Although we have referred to two specific starting systems in which the invention may be used, it should be understood that there are other types of hydraulic starting systems which present the problem which the invention solves. One such system which deserves mention is disclosed in U.S. Patent 3,106,057, granted Oct. 8, 1963. In cases where the cam plate of the motor-pump unit in this prior system is provided with an unbalanced control, i.e., a control which automatically moves the cam plate to a pumping position rather than the neutral position when the accumulator is fully discharged, intolerable oscillations of the cam plate can occur under the two abnormal conditions mentioned earlier. The severity of these oscillations can be reduced by incorporating the present valving device in conduit **75** of the patent so that it serves to maintain motor **53** at the initial charge pressure of the accumulator throughout the starting cycle.

As stated previously, the drawings and description relate only to the preferred and several alternative embodiments of the invention. Since the structures of the these embodiments can be changed in many respects without departing from the inventive concept, the following claims should provide the sole measure of the scope of the invention.

What we claim is:

1. A hydraulic starting and pumping system comprising

(a) an overcenter motor-pump unit having high and low pressure ports and a displacement control element which is movable between positions at opposite sides of a zero displacement position to reverse the direction of flow through the unit;

(b) an accumulator for supplying motive fluid to the motor-pump unit to drive same as a motor;

(c) first conduit means connecting the accumulator with the high pressure port and controlled by a start valve;

(d) a fluid reservoir;

(e) pressure actuated means for positioning the displacement control element and including a fluid pressure motor, a valve having supply and exhaust positions in which, respectively, it connects the motor with the high pressure port and the reservoir, and an actuating motor for holding the valve in one of its positions during the starting cycle;

(f) second conduit means connecting the actuating motor with the first conduit means;

(g) means for permitting flow from the accumulator to the second conduit means only when the start valve is open;

(h) means for preventing flow from the motor-pump unit to the second conduit means;

(i) a check valve in the second conduit means oriented to prevent flow from the actuating motor;

(j) third conduit means connecting the actuating motor with the reservoir;

(k) a vent valve controlling the third conduit means; and

(l) actuating means which closes and opens the vent valve as it opens and closes, respectively, the start valve.

2. A system as defined in claim **1** wherein the means for permitting and preventing flow to the second conduit means comprises a valve which is operated in unison with the start valve and which isolates the second conduit means from the first conduit means when the start valve is closed.

3. A system as defined in claim **1** wherein

(a) the second conduit means is connected with the first conduit means between the start valve and the high pressure port, whereby the start valve serves as said means for permitting flow to the second conduit means; and

(b) said means for preventing flow to the second conduit means comprises a check valve interposed in the first conduit means between the high pressure port and the junction with the second conduit means.

4. A system as defined in claim **1** wherein

(a) the start valve has a main portion which controls flow from the accumulator to the high pressure port of the motor-pump unit, and a piloting portion which controls the operation of the main portion; and

(b) the actuating means includes mechanical means which simultaneously operates both the piloting portion of the start valve and the vent valve.

5. A system as defined in claim **4** wherein

(a) the second conduit means is connected with the first conduit means between the main portion of the start valve and the accumulator, whereby the main portion of the start valve serves as said means for preventing flow from the motor-pump unit to the second conduit means; and

(b) said means for permitting flow from the accumulator to the second conduit means comprises a second valve interposed in the second conduit means between the check valve and the junction with the first conduit means and which is opened and closed by said mechanical means as the latter closes and opens, respectively, the vent valve.

6. A system as defined in claim **4** wherein

(a) the second conduit means is connected with the first conduit means between the main portion of the start valve and the high pressure port, whereby the main portion of the start valve serves as said means for permitting flow from the accumulator to the second conduit means; and

(b) said means for preventing flow from the motor-pump unit to the second conduit means comprises a check valve interposed in the first conduit means between the high pressure port and the junction with the second conduit means.

7. A system as defined in claim **5** which includes means for retarding opening of the main portion of the start valve so that when the actuating means opens the second valve and closes the vent valve the pressure in the actuating motor increases at a faster rate than the pressure at the high pressure port.

8. A system as defined in claim **5** wherein the start valve comprises

(a) a main portion that controls flow from the accumulator to the high pressure port and which is spring biased to a closed position;

(b) a first reaction surface on the main portion which is subject to accumulator pressure and which urges the main portion in the opening direction;

(c) a piloting chamber connected with the accumulator through a first restricted passage;

(d) a second reaction surface on the main portion which is subject to the pressure in the piloting chamber and is arranged to develop a force which urges the main portion in the closing direction;

(e) a second restricted passage connecting the piloting chamber with the reservoir; and

(f) a pilot valve operated by the mechanical means for opening and closing the second restricted passage as the mechanical means closes and opens, respectively, the vent valve;

(g) the flow restriction afforded by the second restricted passage being greater than the restriction to flow from the accumulator to the actuating motor through the second conduit means.

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