June 28, 1960 M. M. HANN ET AL 2,942,421

HYDRAULIC TRANSMISSION

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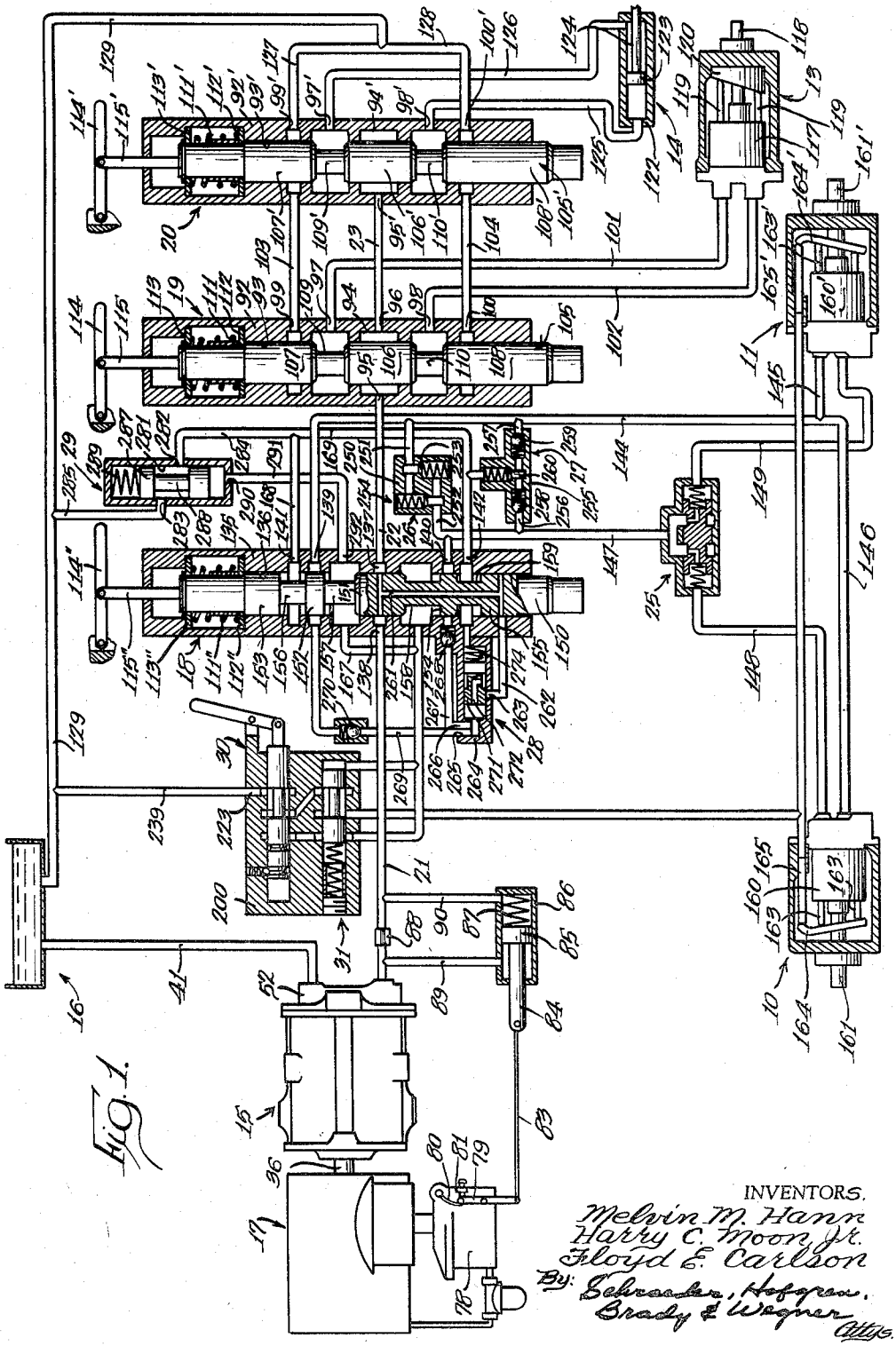


FIG. 1.

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Fig. 2.

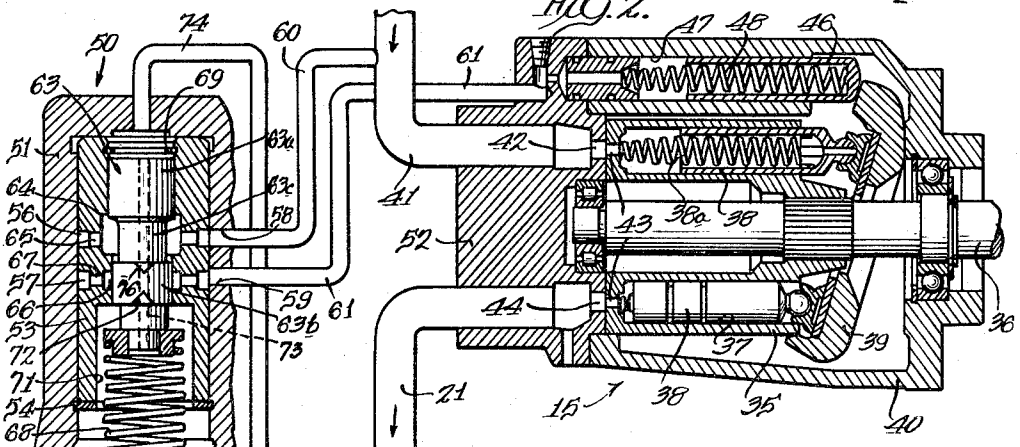
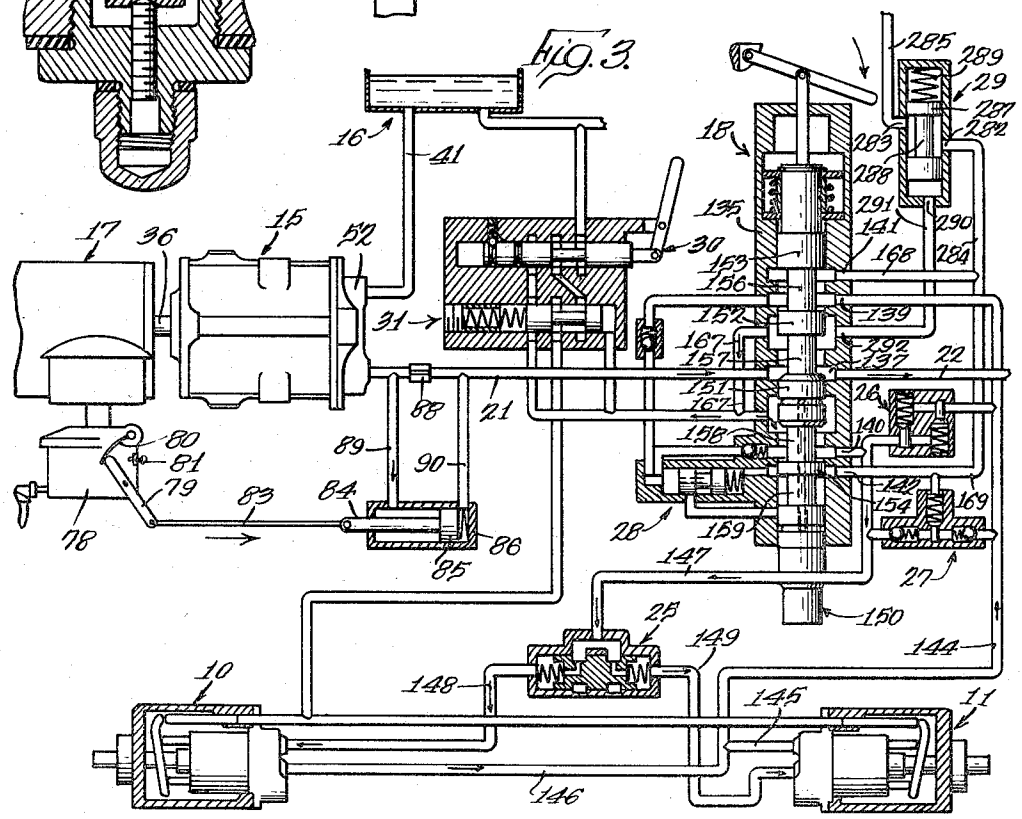


Fig. 3.



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Fig. 5.

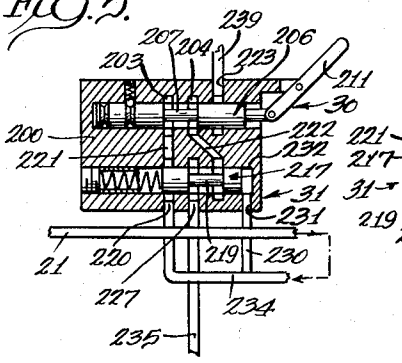


Fig. 4.

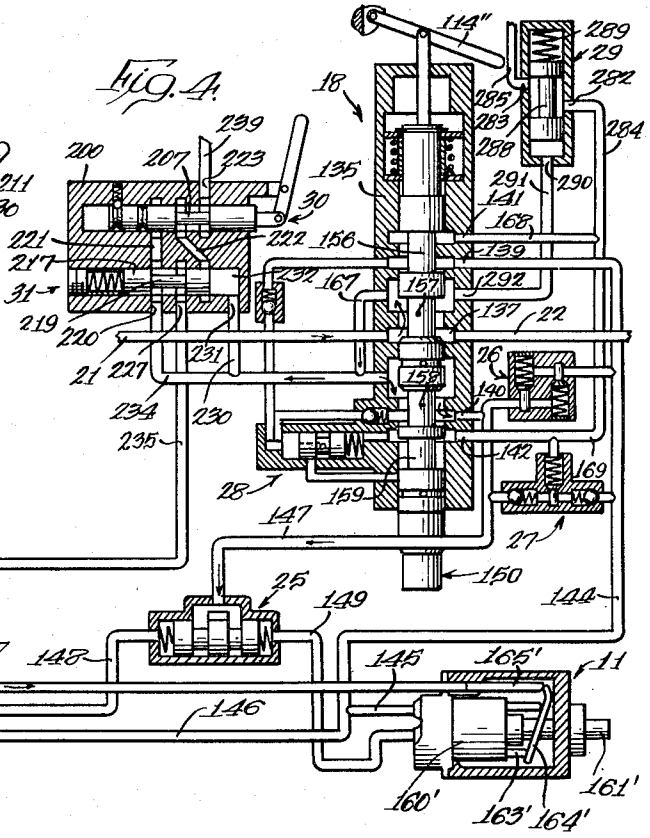


Fig. 6.

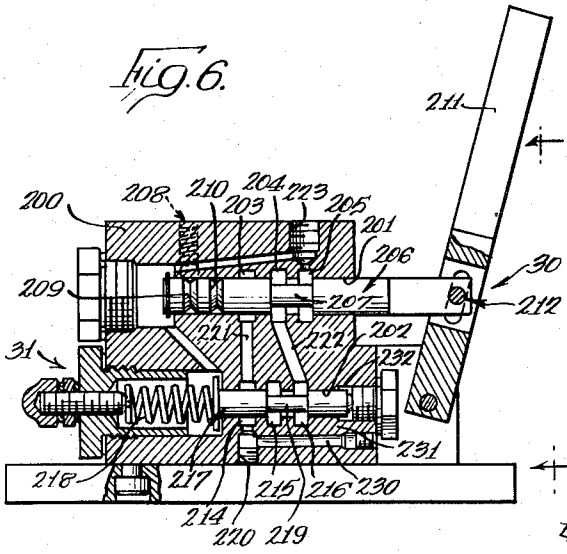
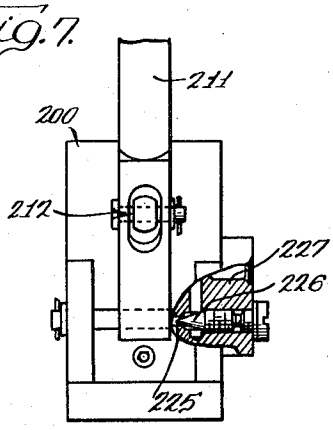


Fig. 7.



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Fig. 8.

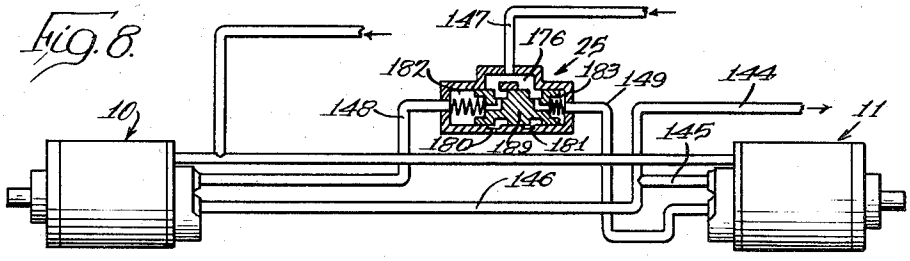


Fig. 9.

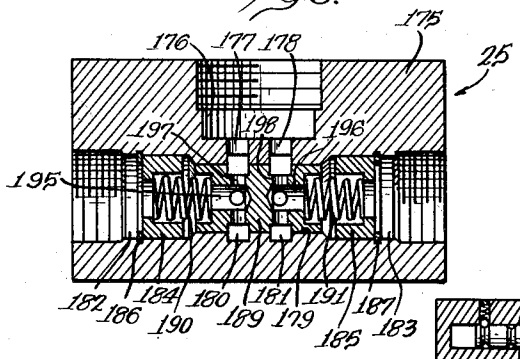


Fig. 10.

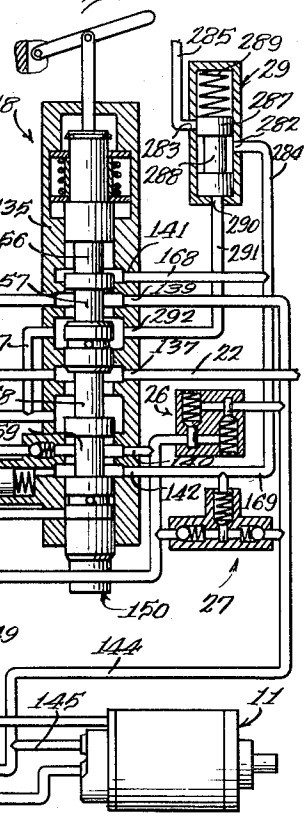
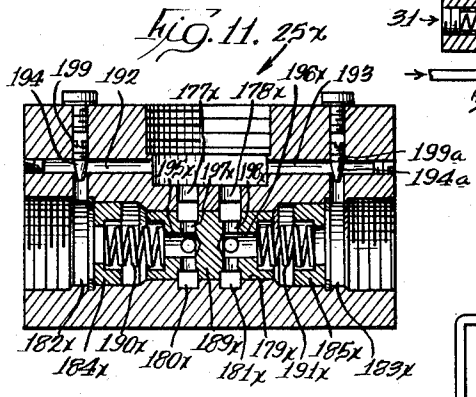


Fig. 11.



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2,942,421

HYDRAULIC TRANSMISSION

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Filed July 31, 1957, Ser. No. 675,340

31 Claims. (Cl. 60—52)

This invention relates to hydraulic systems, and more particularly to hydraulic systems for mobile equipment of the slow moving, hard working types, such as lift trucks and the like.

It is a general object of the invention to provide a new and improved hydraulic system of the character described.

Vehicles of the type described, such as lift trucks, require drive means for propelling the vehicle, usually include a lifting device such as a lift fork, and require means for extending and retracting the lift fork, and means for raising and lowering the lift fork. Machines of this type require maneuverability in close quarters, precise and smooth operation, the ability to withstand high shock loads and overloads, and frequent speed changes and reversals.

With the above and other considerations in mind, it is a more specific object to provide a new and improved hydraulic system for propelling a vehicle such as a lift truck, for extending and retracting a lift device such as a lift fork, and for raising and lowering the lift device.

A further object is to provide a new and improved system of the type described in the preceding paragraph including one or more motors for propelling the vehicle, a reach motor for extending and retracting a lift device, a lift motor for raising and lowering the lift device, means providing a constant pressure, variable volume source of operating fluid, and separately operable valves for the propelling, reach and lift motors respectively, connected in series circuit with the source of fluid and in parallel with each other to permit several operations at one time with independent control of the speed of each individual operation.

It is also an object of the invention to provide a new and improved hydraulic transmission for propelling a vehicle of the type described.

Another object is to provide a new and improved hydraulic transmission system for propelling a vehicle of the type described including at least one propelling motor, means providing a source of operating fluid under pressure, directional valve means for controlling the flow of pressure fluid to the propelling motor, and valve means in the circuit with the propelling motor to restrict the flow of fluid from the motor to thereby provide braking of the motor.

Another object is to provide a new and improved transmission of the type described in the preceding paragraph including braking valve means for braking the propelling motor on slow down of the vehicle and when the vehicle is parked on an incline.

A further object is to provide a new and improved transmission of the type described including braking valve means for braking the propelling motor at any time when the motor attains a speed requiring more flow than is delivered to the motor, as may occur when a downward incline is encountered while operating at full speed.

It is also an object to provide a new and improved hydraulic transmission for propelling a vehicle of the

type described including a variable displacement propelling motor, and means responsive to the load imposed on the propelling motor for varying the displacement of the propelling motor to thereby vary the torque delivered by the motor in response to the variations in the load on the motor.

A further object is to provide a new and improved hydraulic transmission for a lift truck or the like including a variable displacement propelling motor, and manually operable means for varying the displacement of the motor between a low speed, maximum torque value and a high speed, minimum torque value.

Another object is to provide a new and improved hydraulic transmission for a lift truck or the like including two separate propelling motors for driving two separate wheels of the truck, means connecting the motors in series circuit with a source of pressure fluid and in parallel with each other, to permit a differential action between the motors when the truck is turning, and differetnial valve means connecting the two motors and responsive to a differential flow to the motors, as on increased flow to one motor when one vehicle wheel is slipping on a nontractional surface and the other is positioned on a tractional surface, to restrict the flow to the motor driving the slipping wheel and increase the flow to the other motor.

Other objects and advantages will become readily apparent from the following detailed description taken in connection with the accompanying drawings, in which:

Fig. 1 is a hydraulic circuit diagram illustrating a hydraulic transmission system for a lift truck or the like embodying the principles of the present invention, showing the various elements of the system in neutral or normal positions;

Fig. 2 is a fragmentary view of the system, illustrating in detail the pump construction and a control valve incorporated therein for varying the pump displacement automatically to maintain a constant pressure pump discharge;

Fig. 3 is a fragmentary view illustrating the system with the 4-way directional propelling valve shifted to a full speed forward position and with the prime mover carburetor control shifted to a full speed position;

Fig. 4 is a fragmentary view illustrating the system with the propelling valve shifted to a full speed forward position, and with the automatic torque multiplication valve and with the wobbler pistons for the propelling motors shifted to full torque positions;

Fig. 5 is a fragmentary view illustrating the manually controllable torque multiplication valve shifted to a full torque position;

Fig. 6 is an enlarged sectional view, illustrating in detail the construction of the torque valves;

Fig. 7 is an end elevational view, taken at about the line 7—7 of Fig. 6, and partly broken away to illustrate details of the torque valve construction;

Fig. 8 is a fragmentary view, with the differential valve for controlling the propelling motors shifted as when one of the truck propelling wheels slips on a non-tractional surface while the other rests on a tractional surface;

Fig. 9 is an enlarged sectional view, illustrating the construction of the differential valve;

Fig. 10 is a fragmentary view, illustrating the system with the propelling valve shifted to a low speed rearward position, and with the automatic braking valve shifted to an operative position effective to brake the propelling motors;

Fig. 11 is a sectional view similar to Fig. 9, illustrating a modified differential valve.

While several illustrative embodiments of the invention are shown in the drawings and will be described in detail herein, the invention is susceptible of embodiment in

many different forms, and it should be understood that the present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the invention to the embodiment illustrated. The scope of the invention will be pointed out in the appended claims.

According to our invention, a constant pressure, variable volume system is provided including an arrangement of the various valves in parallel circuits for controlling the various operations, to thereby permit several operations at one time with independent control of the speed of each individual operation. For example, the vehicle, such as a lift truck, may be slowly inched forward or backward, and simultaneously, a load may be rapidly hoisted.

The hydraulic system illustrated herein is particularly adapted for use with mobile equipment of the slow moving, hard working type, such as lift trucks and the like. Lift trucks of the type referred to conventionally include thereon a movably mounted lift device, such as a lift fork which is usually mounted for extension and retraction relative to the lift truck to reach and to withdraw from the load. The lift fork is also mounted for movement up and down on the lift truck to hoist and lower the load.

A typical truck of the type referred to includes a truck chassis or frame, a pair of driving wheels supported by one axle of the truck frame, usually near one end of the truck, one or more guiding wheels supported by the truck frame, usually near the other end of the truck, and means supporting the lift device on the truck frame for movement as described. The lift device may comprise a lift fork of generally L-shaped configuration including a generally upright leg and a generally horizontal leg, the latter disposed for movement underneath a load, such as a pallet conventionally employed in warehouses and the like for use in transporting stacked materials from place to place in the warehouses with lift trucks of the character described.

The hydraulic system in general

The hydraulic system illustrated is adapted to be mounted entirely on the truck frame of a lift truck or the like, and includes means for propelling the truck, means for extending and retracting the lift fork, and means for hoisting and lowering the fork. The system illustrated includes the advantages of a precise and smooth control of each operation provided, with an unlimited speed range for each operation, and with a wide variation in torque for the propelling operation. The system also provides for extreme flexibility in installation and may be further utilized for providing a source of fluid under pressure for power steering and other auxiliary hydraulically operated attachments.

Referring now to Fig. 1 particularly, as illustrated, the invention is embodied in a system which includes a pair of hydraulic motors **10** and **11** adapted for connection respectively with a pair of driving wheels of the lift truck for propelling the truck. The motors **10** and **11** are of a variable displacement type in order to provide a wide variation in developed torque, and are reversible in order that the truck may be driven either forwardly or reversely. A third hydraulic motor **13** of a constant displacement type is provided for extending and retracting the lift fork to reach and withdraw from a load, and a hydraulic motor **14** of the reciprocable piston and cylinder type is provided for lifting and lowering the lift fork.

The system includes means providing a source of operating fluid at constant pressure, comprising a variable displacement pump **15** connected to be supplied from a reservoir **16** and adapted to be driven by a variable speed prime mover **17**, such as an internal combustion engine. The pump, the reservoir, and the prime mover are all adapted for mounting on the truck frame and for suitable connection in the hydraulic system. Similarly, the hydraulic motors **10**, **11**, **13** and **14** are also adapted for mounting on the truck frame, for suitable connection in the hydraulic system, and for connection with the devices which they operate.

Operations of the propelling motors **10** and **11**, the reach motor **13**, and the lift motor **14** are controlled respectively by 4-way directional valves, including a propelling valve **18**, a reach valve **19**, and a lift valve **20** which are connected in the system to control the flow of operating pressure fluid to and from the motors.

Operating fluid under pressure is supplied by the pump **15** to the body of the propelling valve **18** through a line **21**, from the body of the propelling valve **18** to the body of the reach valve **19** through a line **22**, and from the body of the reach valve **19** to the body of the lift valve **20** through a line **23**. In this manner, the directional valves are all connected in series with the source of pressure fluid and in parallel with each other, so that operating fluid under pressure from the source is always available at each of the directional valves **18**, **19** and **20**.

The respective motors are connected in series with the associated directional valve and accordingly, the motors may be operated separately, or two or more of them may be operated simultaneously with individual control of the speed of each. While the directional valves have been illustrated as separate structures, it will be appreciated that these may all be made, if desired, in a single body, or the three may be separate and arranged in adjacent relationship in a multiple unit valve stack.

The propelling motors **10** and **11** are connected in series with the propelling valve **18** and in parallel with each other. Flow to these motors from the valve **18** is normally equally divided between the two motors so that the power supplied thereto is the same. The circuit between the valve **18** and the propelling motors includes a differential valve means **25** which functions to divide the flow through the motors **10** and **11** when one of the motors encounters a greater resistance to turning than the other, as when one of the truck driving wheels is positioned on a slippery surface such as ice and the other driving wheel is positioned on a tractional surface. In this case, the differential valve means **25** functions to increase the flow to the motor encountering the greatest resistance to turning and to decrease the flow through the motor having the least resistance ot turning.

The directional valve **18** includes valving described more in detail hereinafter, manually operable, for obstructing the flow of fluid from the propelling motors **10** and **11** thereby to brake the motors when the lift truck is slowed down to a stop or when the truck is parked in neutral on an incline. In order to facilitate the braking of the propelling motors, the circuit connected with these motors includes a braking relief valve means **26**, an over pressure relief valve means **27**, and a makeup valve means **28**, the latter of which functions to maintain the braking circuit charged with a supply of fluid. Also, the propelling motors circuit includes an automatic braking valve means **29** which functions to obstruct the flow of fluid from the propelling motors and thereby brake the motors at any time when these motors require a flow greater than that provided by the source, as when the motors tend to overrun at a time when the truck encounters a downward incline.

As previously noted, the propelling motors **10** and **11** are of the variable displacement type, and this characteristic is utilized to operate the motors either at a minimum displacement, high speed, and low torque, or at a maximum displacement, low speed, and high torque. Operation of the motors in this fashion may be controlled either by a manual torque valve means **30** for controlling the displacement of the motors or by an automatic torque valve means **31** for controlling the displacement of the motors.

System in detail

Referring now particularly to Fig. 2, the pump **15** may

be of a construction including a rotatable cylinder block 35 suitably keyed to a pump drive shaft 36 for rotation therewith. The cylinder block is formed with an annular series of axially disposed cylinders 37 which receive therein axially reciprocal pistons 38 biased outwardly of the cylinder block by springs 38*a*. The pistons 38, through the medium of suitable bearing shoe apparatus, bear against an adjustable angle swash plate 39 non-rotatably held in the pump housing 40. On rotation of the cylinder block 35, in a conventional manner, the pump cylinders 37 take fluid in from an inlet conduit 41 through an intake kidney 42 provided in the pump housing, and through individual cylinder ports 43. The pump cylinders 37 discharge through the individual ports 43, through a discharge kidney 44 to the pump outlet line 21.

The variable angle swash plate 39 is normally biased to a minimum displacement position by means inherent in its mounting and by means of the piston springs 38*a*. Means is provided to vary the angle of the swash plate, and this means partakes of a displacement varying control piston 46 mounted in a control cylinder 47 in the pump housing 40, and biased against the swash plate by means of a spring 48. When the control cylinder 47 is connected to drain, the swash plate 39 will assume a minimum displacement position. Control fluid under pressure may be admitted to the cylinder 47 to increase the swash plate angle and thereby increase the pump displacement.

Control valve means 50 is provided to control the flow of pressure fluid to and from the cylinder 47 in response to the pump discharge pressure in the line 21 to thereby control the pump displacement to produce a constant pressure pump discharge. The control valve means 50 includes a valve body 51 which desirably may be integral with the pump housing end plate 52. It is because the control valve means is provided in the pump end plate 52 that the valve means does not appear separately in the circuit diagram of Fig. 1. The body 51 is formed with a bore having a valve sleeve 53 retained therein by means of a snap ring 54. The valve sleeve 53 is formed with external grooves 56 and 57 which register respectively with ports 58 and 59 in the valve body 51. The port 58 is connected by a conduit 60 to the pump intake line 41, and the port 59 is connected by a conduit 61 to the control cylinder 47.

The valve sleeve includes a bore which slidably receives a control valve member 63 having an upper end portion 63*a* of a predetermined diameter, a lower valve land portion 63*b* of a lesser diameter, and a reduced portion 63*c* between the portions 63*a* and 63*b*. The sleeve bore is formed with an internal groove 64 which communicates with the external groove 56 through radial ports 65 and an internal groove 66 which communicates with the external groove 57 through radial ports 67.

The control valve member 63 is normally biased upwardly as illustrated by a spring 68 which normally positions the valve member against a retaining ring 69 in the valve sleeve bore. When the valve is so positioned, the internal sleeve groove 66 communicates with a sleeve bore 71 through external, inverted V-shaped recesses 72 on the valve land 63*b*. The sleeve bore 71 in turn communicates through a valve member bore 73 with a conduit 74 leading from the valve body 51 to the pump discharge line 21. The variable displacement control cylinder 47 is thereby connected to pump discharge pressure.

If the pump is started now, with each of the directional valves 18, 19 and 20 closed, pressure in the line 21 will immediately build up. Such discharge pressure, through the conduit 74, acts against the upper, relatively large end surface of the control valve member portion 63*a* to force the valve member downwardly against the bias of the spring 68 and the pressure of fluid in the bore 71. Movement of the valve member will continue under these conditions until such time as the internal sleeve groove 66 communicates with external V-shaped recesses 76 on the valve member 63. The recesses 76 in turn communicate, through the reduced portion 63c, with the internal sleeve groove 64. The variable displacement control cylinder 47 is thereby connected to drain through the conduit 60. If the pump is operating under these conditions, the swash plate will be positioned at a minimum displacement angle.

If now, one of the directional valves 18, 19 or 20 is opened, there will immediately occur a pressure drop in the pump discharge line 21. This relieves the pressure acting against the upper end of the control valve member 63 and the spring 68 is effective to force the valve member upwardly. The variable displacement control cylinder 47 is thereby connected to pump discharge pressure through conduit 74, the valve member bore 73, the external recesses 72 on the valve member and the conduit 61. Fluid pressure is then effective to force the control piston 46 outwardly of the cylinder 47, increasing the swash plate angle and the pump displacement.

The operation described is effective to maintain a substantially constant fluid pressure in the pump discharge line 21.

Referring again to Fig. 1, the pump drive shaft 36 is connected to be driven by the prime mover 17 which may comprise an internal combustion engine of a conventional type. The speed of the engine 17 is controlled by a fuel feed device such as a carburetor 78. The carburetor is controlled by a mechanism including a lever 79 normally biased by a leaf spring 80 against an adjustable stop 81 so as to normally supply sufficient fuel to the engine 17 to support its operation at an idle speed.

The carburetor lever 79 is automatically controlled to increase the fuel feed to the engine 17, and thereby increase the engine speed, in response to increased flow in the pump discharge line 21. Control of the carburetor is effected by means of a link 83 connected with the carburetor lever 79 and also connected with the piston rod 84 of a piston 85 reciprocal in a cylinder 86. The piston 85 is normally biased toward an idle position by means of a spring 87 which acts in conjunction with the leaf spring 80.

A restrictive orifice 88 is provided in the pump discharge line 21, and the pressure drop across the orifice 88 is utilized to control the position of the piston 85 in accordance with the flow rate in the pump discharge line 21. To this end, a conduit 89 is connected to the pump discharge line 21 ahead of the orifice 88 and to the cylinder 86 on one side of the piston 85. Another conduit 90 is connected to the pump discharge line 21 down stream of the orifice 88 and is connected to the cylinder 86 on the opposite side of the piston 85.

In response to an increased flow through the line 21, there occurs an increased pressure drop across the orifice 88. The pressure in the line 89 and on the left-hand side of the piston 85 accordingly increases with respect to the pressure in the line 90 and on the right side of the piston 85, forcing the piston to the right, as illustrated in Fig. 3, thereby increasing the speed of the engine 17. As illustrated in Fig. 3, this action would occur after one of the directional valves, such as the valve 18, is opened requiring an increased flow. In order to maintain the system pressure constant, the speed of the prime mover is increased along with an increase in pump displacement. If now, the valve 18 is closed, the pressure down stream from the orifice 88 will become equal to that upstream of the orifice, and the piston 85 will return toward its original position thereby reducing the speed of the engine 17.

The load on the engine 17 driving the pump 15 is directly proportional to the flow from the pump. Thus, the means described for controlling the engine speed is effective to sense the pump displacement and to modulate the speed of the engine in accordance with the varying load demands thereon. The design of the piston 85 and the strength of the springs controlling the piston are calculated so as to match the torque output of the engine

with the flow requirements of the hydraulic system, and thus permit economic operation of the engine only at a speed required for any given load condition.

As previously noted, pressure fluid from the pump discharge line **21** flows to the body of the directional valve **18**, thence to the directional valve **19**, then to the valve **20** so that pressure fluid is always available at each of the valves to permit propelling, reaching, or hoisting, either separately or simultaneously.

The directional valve **19** for controlling the reach motor **13** includes a valve body **92** having an elongated bore **93** which is provided with a centrally disposed annular groove **94**. The groove **94** is provided with an inlet port **95** which communicates with the pressure conduit **22** from the valve **18**, and includes an outlet port **96** which communicates with the pressure conduit **23** with the valve **20**. The valve body is also formed with a pair of motor ports **97** and **98** disposed respectively on opposite sides of the centrally annular groove **94** and drain ports **99** and **100** near opposite ends respectively of the bore **93**. A conduit **101** leads from the motor port **97** to the motor **13**, and the conduit **102** leads from the motor port **98** to the motor **13**. Drain ports **99** and **100** are connected with conduits **103** and **104** respectively which lead to drain grooves in the valve **20**.

A valve stem **105** is slidably disposed in the valve bore **93**. The stem **105** includes three spaced lands including a central land **106**, an upper land **107** and a lower land **108**. The lands are separated by reduced portions of the stem including an upper reduced portion **109** and a lower reduced portion **110**.

The valve stem is biased to a neutral center position illustrated in Fig. 1 by means of a spring **111**. The spring bears against a lower collar **112** and an upper collar **113**, both slidable on the valve stem and both slidable in an enlarged portion of the valve body bore. The collars **112** and **113** are both adapted to bear against shoulders formed on the valve stem and on the valve body in a manner to permit movement of the valve stem in opposite directions from the neutral center position shown in two operative positions, one for effecting operation of the reach motor forwardly and one for effecting operation of the reach motor reversely. Movement of the valve stem may be effected by manually operable means including a handle **114** pivotally mounted on the valve body structure and having a suitable pin and slot connection with the rod **115** extending upwardly from the valve stem **105**.

The reach motor **13** may be of a conventional type including a rotatable cylinder block **117** connected to drive an output shaft **118** and having axially reciprocal pistons **119** bearing against a fixed angle swash plate **120**. The construction of the motor **13** is such that it may be operated forwardly or reversely by reversing the direction of flow through the motor.

Operation of the reach motor **13** forwardly is obtained by moving the valve stem **105** upwardly from the position illustrated in Fig. 1 to a position in which the stem groove **110** connects the valve inlet port **95** and the motor port **98**. In this case, the fluid from the motor **13** flows into the valve **19** through the motor port **97** and passes to drain through the stem groove **109** and the drain port **99**.

Operation of the reach motor reversely is obtained by movement of the valve stem **105** downwardly from the position illustrated to connect the valve inlet port **95** with the motor port **97** through stem groove **109**. In this case, fluid flows from the motor **13** into the valve **19** through motor port **98**, and passes to drain through the stem groove **110** and the drain port **100**. The speed of operation of the motor **13** may be controlled by the amount of valve opening movement of the stem **105**.

The construction of the lift valve **20** is substantially identical with that of the valve **19**, and accordingly will not be described in detail. The elements of the valve **20** which find their equivalents in the valve **19** are identified by similar reference numbers which are primed. Fluid flows into the valve **20** through an inlet port **95'** which communicates with the pressure conduit **23**. The valve **20** does not include an outlet port equivalent to the outlet port **96** in the valve **19** since none is necessary, the valve **20** being the last of the group.

The lift motor **14** may be of a conventional piston and cylinder type including a cylinder **122** having a piston **123** reciprocable therein and having a piston rod **124** adapted to be connected with the lift fork of the lift truck.

In order to elevate the lift fork, the valve stem **105'** is moved upwardly from the position illustrated in Fig. 1 to a position connecting the inlet port **95'** to the motor port **98'** through the stem groove **110'**, thereby admitting fluid to the left end of the left cylinder **122** through a conduit **125**. At the same time, the right end of the left cylinder is connected to drain through a conduit **126**, motor port **97'**, the stem groove **109'**, and drain port **99'**. The drain ports **99'** and **100'** are connected by conduits **127** and **128** which merge and are connected to the reservoir **16** by conduit **129**.

Lowering of the lift fork is obtained by movement of the valve stem **105'** downwardly from the position illustrated in Fig. 1 to admit pressure fluid to the right end of the left cylinder **122** and to connect the left end of the cylinder to drain, as will be understood. The speed of operation of the lift motor **14** may be controlled by valve opening movement of the stem **105'**, or other means may be provided to meter the flow to control the speed.

The propelling motors circuit in detail

The directional valve **18** for controlling operation of the propelling motors **10** and **11** includes a valve body **135** formed with a central longitudinal bore **136** which includes a centrally disposed annular inlet groove **137**. The groove **137** has an inlet port **138** communicating with the pressure line **21**, and an outlet port communicating with the pressure conduit **22**. The valve body **135** is also formed with a pair of motor ports **139** and **140** disposed respectively on opposite sides of the central annular groove **137**. Drain ports **141** and **142** are provided in the valve body near opposite ends respectively of the bore **136**.

The motor port **139** is connected with a conduit **144** which in turn is connected with branch conduits **145** and **146** leading respectively to the propelling motors **11** and **10**. The motor port **140** is connected to a conduit **147** leading to the differential valve means **25** which in turn is connected to branch conduits **148** and **149** leading respectively to the propelling motors **10** and **11**.

A valve stem **150** is slidably disposed in the valve bore **136** for movement in opposite directions from the neutral center position illustrated in Fig. 1 to two operative positions, one for effecting operation of the propelling motors forwardly, and one for effecting operation of the propelling motors reversely. The stem **150** is formed with enlarged portions or lands thereon, including a centrally disposed land **151**, two lands **152** and **153** disposed upwardly on the stem from the center land, and similarly, two lands **154** and **155** disposed downwardly on the stem from the center land **151**. The five lands referred to are separated by outer stem grooves **156**, **157**, **158** and **159**.

Movement of the valve stem **150** is controlled by means similar to that utilized for controlling the operation of the valve stem **105** in the directional valve **119** and identified by similar reference numbers double primed.

The propelling motors **10** and **11** may be of a similar conventional construction. Since the motors are identical, only motor **10** will be described in detail. Similar reference numbers are used to designate similar parts in the motor **11** with a prime suffix. The motor **10** includes a rotatable cylinder block **160** connected to drive the motor output shaft **161**. The cylinder block **160** is formed with an annular series of cylinders housing reciprocable pistons **163** which bear against a variable angle swash plate **164**.

A control piston 165 is reciprocable in the motor housing to vary the angle of the swash plate 164.

Operation of the propelling motors 10 and 11 forwardly is obtained by delivering pressure fluid to the motor conduit 147. The differential valve means 25 normally functions to divide the flow from the conduit 147 and deliver equal flows to the conduits 148 and 149 to obtain identical operation of the motors 10 and 11. In order to obtain operation of the motors 10 and 11 forwardly, the valve stem 150 is moved downwardly from the neutral center position illustrated in Fig. 1 to the position illustrated in Fig. 3. With the valve member positioned as illustrated in Fig. 3, the fluid under pressure enters the valve 18 from the pressure conduit 21 at the central valve body groove 137, passes through the stem groove 157 to conduit 167 which may if desired be formed in the valve body 135 alongside the main valve bore 136. The fluid passes from the conduit 167 into the main valve bore 135, through the stem groove 158, to the motor port 140, and thence to the propelling motors. The flow from the motors 10 and 11 passes to conduits 145 and 146, conduit 144 and to the motor port 139. From the motor port 139 fluid passes to drain through stem groove 156, the drain port 141, and a drain passage 168. As illustrated in Fig. 3, the directional valve 18 has been moved to a fully open position for obtaining operation of the propelling motors at full speed in a forward direction.

Operation of the propelling motors 10 and 11 reversely is obtained by movement of the valve stem 150 upwardly of the neutral position illustrated in Fig. 1 to the position illustrated in Fig. 10. When the valve is positioned as illustrated in Fig. 10, pressure fluid flows from the pressure conduit 21 to the valve bore, stem groove 158, conduit 167, and stem groove 157 to the motor port 139. The flow from the motor port 139 is through conduit 144 and branch conduits 145 and 146 which serve to divide the flow equally to the two motors. The flow from the motors 10 and 11 passes through branch conduits 148 and 149 to the differential valve means 25, conduit 147, motor port 140, stem groove 159, drain port 142, and a drain conduit 169. As illustrated in Fig. 10, the valve stem is positioned to obtain full speed operation of the motors 10 and 11 in a reverse direction. A low speed operation of the motors may be obtained by moving the valve stem only sufficiently to obtain a partial valve opening.

It will be noted that the propelling motors 10 and 11 are connected in series with the source of operating fluid, and in parallel with each other. With the motors arranged in parallel as illustrated, a differential action is provided at the motors, which permits a relative movement between the two when the lift truck is being driven and is turned so that one of the driven wheels moves in an arc of greater radius than the other.

While the differential action thus provided gives rise to certain advantages, the connection of the motors in parallel may also give rise to certain disadvantages. More specifically, if one of the driving wheels is positioned on a slippery surface, such as ice or oil, while the other wheel is positioned on a tractional surface, the flow of oil from the source will of course take the path of least resistance, and a greater portion of the flow will pass through the motor having the least resistance to turning with the result that the wheel positioned on the slippery surface will spin and the flow to the other motor will be insufficient to propel the lift truck. In order to overcome this difficulty, the differential valve means 25, previously referred to in general, is provided to produce a differential flow through the motors, providing an increased flow to the motor having the greatest resistance to turning and a decreased flow through the motor having the least resistance to turning. In this manner, the flow to the motor driving the wheel on a tractional surface will be sufficient to propel the truck.

Referring now particularly to Figs. 8 and 9 for a detailed description of the differential valve 25, it will be seen that the valve comprises a valve body 175 having

a chamber 176 to which the conduit 147 leads from the directional valve 18. The chamber 176 is formed with two ports 177 and 178 which lead to a transversely extending bore 179 in the valve body having annular grooves 180 and 181 which register with the ports 177 and 178, respectively. The bore 179 terminates at opposite ends of the valve body in chambers 182 and 183 which may be termed inlet or outlet chambers, and which communicate respectively with motor conduits 148 and 149. A pair of similar sleeves 184 and 185 are positioned one in each of the chambers 182 and 183. The sleeves are retained in position by retaining rings 186 and 187.

A valve member 189 is slidably positioned in the valve bore 179 between the two plugs 184 and 185. The valve member 189 is normally retained in a centered position by oppositely acting springs 190 and 191, each of which bears at one end against a shoulder on the valve member and at the opposite end against a shoulder formed on the adjacent sleeve. The valve member 189 is formed with a pair of longitudinally extending bores 195 and 196 opening respectively at opposite ends of the valve member. These bores, 195 and 196, provide orifices interconnecting radial passages 197 and 198 with the interior of the sleeves 184 and 185.

Under normal operating conditions, with the motors 10 and 11 driven either forwardly or reversely, with equal flows passing through the two motors, the valve member 189 will occupy a neutral center position, as illustrated in Fig. 9, under the urge of the centering springs 190 and 191. With the valve positioned as illustrated in Fig. 9, it will be clear that whether the flow enters the valve body at the chamber 176 or at the chambers 182 and 183, the valve member 189 is positioned such that the flow through the two motors is equal.

If, with the propelling motors 10 and 11 operating in a forward direction, and with the differential valve member 189 positioned as illustrated in Figs. 1, 3, 4 and 9, one of the wheels driven by the propelling motors encounters a slippery surface, the differential valve 25 will come into play. Let it be assumed that with the propelling motors operating forwardly, the truck wheel driven by the motor 11 encounters a slippery surface, while the wheel driven by the motor 10 is on a tractional surface. In this case, the motor 10 under heavy load will have a substantially greater resistance to turning than will the motor 11 which is only lightly loaded. As a consequence, the operating fluid, taking the path of least resistance, flows in substantially greater quantities (ten times greater, for example) to the motor 11 than to the motor 10, leaving insufficient fluid and pressure to drive motor 10, and the pressure downstream of the orifice 196 falls greatly relative to the pressure downstream of the orifice 195. This differential pressure, operating against opposite sides of the valve member 189, serves to shift the valve member 189 from the position illustrated in Fig. 9 to the position illustrated in Fig. 8. This movement of the valve member 189, in closing the bore grooves 180 and 181 forms a restricted orifice, which reduces the flow of fluid to the lightly loaded motor 11 to a value substantially less than the total flow of fluid from the pump, leaving quantities for flow to motor 10. While the path of flow to the motor 10 also becomes restricted by partial closure of the groove 180, the restrictions in the flow paths of the operating fluid cause an increase in the pressure of the operating fluid and fluid under higher pressure will now flow to the motor 10. The flow which now passes to the motor 10 will be at sufficient pressure to propel the truck to move it off of the slippery surface. When the motor 11 again is loaded similarly with the motor 10, valve member 189 is returned by the spring 191 to the neutral center position illustrated in Fig. 9.

The amount of fluid which is permitted to flow to the motor 11 when the valve member 189 is positioned as illustrated in Fig. 8, is determined by the amount of

movement of the valve member **189** relative to the bore grooves **180** and **181**. The amount of valve movement permitted may be regulated by the length of the sleeve members **184** and **185** which act as stop members limiting valve movement. The sleeves may be removed and replaced by sleeves of shorter or greater length to thereby vary the length of valve movement permitted and accordingly decrease or increase the size of the restrictive orifices formed at the grooves **180** and **181**.

The condition of the circuit and the position of the valve member **189**, illustrated in Fig. 8, also represents the circuit conditions when the motors **10** and **11** are driven reversely and the truck wheel driven by the motor **10** encounters a slippery surface with the motor **11** heavily loaded with its wheel on a tractional surface. In this case, the flow of fluid will be to the motors through the conduit **144** and from the motors through the conduit **147**. Under these conditions, since the motor **10** is only lightly loaded, the flow through this motor is much greater than that through the motor **11**. Consequently, the increased flow through the conduit **148** relative to the flow through the conduit **149** gives rise to an increased pressure in the inlet chamber **182**, forcing the valve member **189** to the position illustrated in Fig. 8.

If desired, the plugs which limit movement of the valve member may be of a length which will permit movement of the valve member to a position completely blocking the flow of fluid therethrough. In this case, the valve body is formed with passages bypassing the valve member and provided with adjustable orifices which restrict the flow to the unloaded motor when the valve is closed. Such a modified structure is illustrated in Fig. 11, wherein the parts which correspond to similar parts in Fig. 9 have been identified by similar reference numbers with a suffix "*x*."

As seen in Fig. 11, plugs **184***x* and **185***x* permit movement of valve member **189***x* to the right or left from the neutral position illustrated, depending on the direction of rotation of the motors and depending on which motor is unloaded, to positions completely blocking the flow of fluid through the valve member. Valve body **175***x* is formed with passages **192** and **193**, bypassing the valve member **189***x*, and leading from the chamber **176***x* to the chambers **182***x* and **183***x* respectively. The passages **192** and **193** are provided with variable orifices **194** and **194***a* respectively, which are formed in part by adjustable needle valve members **199** and **199***a*, respectively. The adjustable orifices **194** and **194***a* thus would function to meter the flow to the unloaded motor, thereby providing a flow to the loaded motor. The advantage of this construction resides in the fact that the adjustable needle valve members **199** and **199***a* may be positioned for access exteriorly of the valve body **175***x* to permit adjustment without the necessity of disassembly.

Also, it will be appreciated that the desired results may be obtained by other valve means as well. For example, means may be provided whereby the flow to the unloaded motor is restricted substantially while leaving the passages to the loaded motor completely unrestricted.

As previously noted, the propelling motors **10** and **11** are variable displacement motors, and this characteristic of the motors is utilized, in combination with the torque multiplication valve means **30** and **31**, previously referred to, to obtain the optimum usage of a small prime mover, enabling the reduction in size of a lift truck or the like where maneuverability in close quarters is so essential. With the hydraulic system illustrated, the optimum size prime mover, such as the engine **17**, is one that will provide just enough power to maintain the vehicle at full speed with a full load on a level surface with no reserve power to climb an incline or a ramp. The automatic torque multiplication valve **31** enables the practical use of a small prime mover engine by automatically sensing an overload condition on the motors **10** and **11** to automatically increase the displacement of the motors, thereby providing an increased torque output and a reduction of the speed of the motors. Additionally, the displacement of the propelling motors may be controlled manually in order to obtain a low speed operation for "inching" the truck along at a slow speed.

The torque valve means includes a valve block **200** incorporating both the automatic torque valve **31** and the manual torque valve **30**. As illustrated in Figs. 6 and 7, the valve block **200** is formed with two parallel bores **201** and **202**. The bore **201** is formed with three longitudinally spaced annular grooves **203**, **204** and **205**, and receives a slidable valve member **206** which is manually operable.

The valve member **206** is formed with a centrally disposed reduced portion **207** which connects the two grooves **204** and **205** when the valve stem is positioned as illustrated in Fig. 6. The valve member **206** is retained in the position illustrated by means of a spring pressed detent **208** which engages with a groove **209** on the valve stem. The stem **206** is movable to the left as viewed in Fig. 6 to a position illustrated in Fig. 5 wherein the stem groove **207** connects the two valve bore grooves **203** and **204**. In the latter position, the stem is retained by engagement of the detent **208** in a stem groove **210**. Operation of the member **206** is obtained by a pivotally mounted handle **211** having a pin and slot connection **212** with the valve stem.

The valve bore **202** is formed with three spaced annular grooves **214**, **215** and **216**. A valve stem **217** is slidably positioned in the bore **202**, and normally urged to the position illustrated in Fig. 6 by spring **218**. In the position illustrated, a centrally disposed reduced portion **219** on the valve stem connects the bore grooves **215** and **216**.

The groove **214** in the bore **202** connects with an outlet port **220** from the valve body adapted to be connected to a pressure conduit. The groove **214** also is connected by a passage **221** with the groove **203** in the bore **201**. The groove **216** in the bore **202** is connected by a passage **222** to the groove **204** in the bore **201**. The third groove **205** in the bore **201** is connected to a drain port **223** in the valve block. The third groove **215** in the valve bore **202** communicates through a laterally extending passage **225** (Fig. 7) and an adjustable needle valve **226** with an outlet port **227**. The pressure port **220** in the valve block is connected by a passage **230** and a passage **231** with an enlarged end portion **232** of the valve bore **202** to supply fluid pressure to the end of the valve stem **217** for obtaining automatic operation of this valve.

As seen in Figs. 4 and 5, the pressure port **220** leading into the valve block **200** is connected by conduit **234** which is in turn connected with the pressure conduit **167**, so that whenever the directional valve **18** is opened in either direction from neutral, pressure fluid is delivered to the valve block **200**, to the valve grooves **214** and **203**. Also, in Figs. 4 and 5, it will be seen that the outlet port **227** from the valve block **200** is connected by a conduit **235** and branch conduits **236** and **237** to supply fluid under pressure from the valve block to effect movement of the control pistons **165** and **165'** in the motors **10** and **11**. As seen in Fig. 1, the drain port **223** from the valve block **200** is connected by a conduit **239** with the drain conduit **129**.

In operation, the valve members **206** and **217** are normally positioned as illustrated in Fig. 6, so that the control pistons **165** are connected to drain through the conduit **235**, the port **227**, stem groove **219**, passage **222**, stem groove **207**, and conduit **223**. With the direction valve positioned as illustrated in Fig. 4, the motors **10** and **11** are operated full speed in a forward direction. In the event that the motors encounter an undue resistance to turning, as when the wheels driven thereby encounter an obstruction or an incline, the resistance to turning causes a pressure rise in the pressure conduit **147**, in the passage **167**, in the conduit **234**, in the pressure

port 220, in the passages 203 and 213, and in the valve bore 232. The increased pressure causes movement of the valve member 217 to the position illustrated in Fig. 4, wherein the pressure port 220 is connected by the stem groove 219 to the outlet port 227 in the valve block 200. Pressure fluid is thus applied to the conduit 235 and to actuate the control pistons 165 and 165', shifting the swash plates 164 and 164' to a maximum angle providing maximum pump displacement, maximum torque at the motors, and minimum speed.

If the resistance of the motors 10 and 11 to turn decreases, there will be a pressure drop in the system which permits return of the valve member 217 to the normal position illustrated in Fig. 6, thereby connecting the control pistons 165 to drain. This permits return of the swash plates to a minimum displacement angle providing high speed and minimum torque.

Manual control of the displacement of the motors is provided by shifting the valve member 206 from the normal position illustrated in Fig. 6 to the position illustrated in Fig. 5. In the latter position, pressure fluid is supplied to the control pistons 165 through the pressure port 220, the passage 221, stem groove 207, passage 222, stem groove 219, outlet port 227, and the conduit 235.

The operation of the automatic torque valve 217 is as follows. At a given flow rate and pressure, the torque output of the engine 17 is absorbed by the pump 15, and the torque multiplication valve and the variable displacement motors permit these operating conditions to remain constant, with the propelling motors operating at a maximum speed with minimum torque output. When an obstruction or a ramp is encountered, the system pressure would normally rise to meet the overload condition on the propelling motors. The tendency toward a pressure rise in the system is sensed by the valve 217 to increase the displacement of the propelling motors from a minimum displacement to a maximum displacement, while maintaining the system pressure constant. Increase in the motor displacement while holding the pressure and flow constant results in an increased torque delivery by the motors, the torque increasing in direct proportion with the displacement, and the speed of the motors varying inversely as the displacement of the motors. The lift truck on encountering a ramp or the like thus automatically modulates speed and torque until the speed reduces to a minimum, and a maximum torque is provided. After the ramp is negotiated, the motors automatically regain speed when the overload condition is eliminated.

Manual operation of the torque valve 206 enables an accurate control of the propelling motors at very low speeds. This valve, when shifted to the position of Fig. 5, holds the propelling motors in maximum displacement, resulting in minimum speed and maximum torque at the drive wheels. The vehicle may thereby be "inched" along. The propelling motors, operating at maximum displacement, enable the truck to roll over an obstruction without a reduction in speed, the increased load to climb the obstruction producing merely a slight rise in system pressure. Thus, the operator is enabled to maintain precise speed control in close quarters regardless of the condition of the floor or terrain on which the truck is operated.

According to the present invention, manually controllable means is provided for braking the propelling motors when the lift truck is parked in neutral on an incline and to brake the propelling motors on slowdown to a stop. Also, means is provided to automatically brake the propelling motors at any time when the motors tend to overrun at a speed requiring a greater fluid flow through the motors than that provided by the source of pressure fluid. The last mentioned braking means therefore functions especially during propelling of the vehicle, as at high or low speed in either direction, when a downwardly inclined ramp or the like is encountered.

Referring now particularly to Fig. 1, the manually controllable directional valve 18 for controlling the propelling motors 10 and 11 includes valving for braking the propelling motors on slowdown and in neutral. Principally, the valving referred to comprises the lands 152 and 154 on the valve stem 150. When the valve stem 150 is positioned as illustrated in Fig. 1, the land 152 serves to block the motor port 139, and the land 154 serves to block the motor port 140. Thus, if the truck is parked on an incline, facing either forwardly or reversely, the weight of the truck and any load carried thereby will tend to cause the truck to roll down the ramp. Such a condition causes the propelling motors 10 and 11 to function as pumps. But, inasmuch as both motor ports 139 and 140 are blocked, the propelling motors, when rotated in either direction pump against a blocked passage. Obviously this restricts the flow of fluid from the motors, and brakes the motors.

Similarly, the valving described also functions to brake the propelling motors on slowdown. Thus, if, while operating the propelling motors forwardly as described in connection with Fig. 3, the valve stem 150 is returned from the position illustrated in Fig. 3 toward the position illustrated in Fig. 1, the valving described will function to brake the motors.

The operation is as follows. On slowdown, the flow of pressure fluid to the propelling motors is reduced, thus tending to slow the motors. But, the inertia of the rolling truck tends to maintain the truck, momentarily at least, at the initial speed. The motors thus being to function as pumps, pumping more fluid than that delivered to the motors, and pumping against the partially closed directional valve. Thus, the land 152 or the land 154, depending on the direction of movement, tend to restrict the flow from the motors and to brake the motors. If the valve stem 150 is moved completely to the neutral position the lands 152 and 154 completely block the flow from the motors as described previously.

The braking relief valve means 26, previously referred to in general, is provided to maintain the braking pressure in the motor return line 144 or 147, depending on the direction of truck movement. This valve means functions to bypass fluid from the motor return line to the motor inlet line to regulate the braking pressure and at the same time maintain hydraulic fluid in the braking circuit.

As seen in Fig. 1, for example, the braking valve means 26 includes a valve body 250 having a first conduit 251 connected to the motor conduit 144 and a second conduit 252 connected with the motor conduit 147. The valve body 250 is also provided with two valve bores, one bore housing a spring pressed check valve 253 biased to a closed position against the pressure of fluid in the conduit 251. The second bore houses a spring pressed check valve 254 biased to a closed position against the pressure of fluid in the conduit 252. Passages provided in the valve body enable the valve 253 to deliver fluid from the conduit 251 to the conduit 252, and additional passages enable the valve 254 to deliver fluid from the conduit 252 to the conduit 251.

In operation, assuming the truck is parked in neutral, as illustrated in Fig. 1, on an incline such that the truck tends to roll forwardly, the motors 10 and 11 tend to function as pumps, drawing fluid in through the motor conduit 147 and pumping the fluid out through the conduit 144. In this case, the land 152 blocks the flow of fluid from the motors, the valve 254 is held closed by its biasing spring and by the pressure of fluid in conduit 251, and the valve 253 is biased toward a closed position by its spring. The valve 253 will thus maintain the braking pressure in the line 144 up to a predetermined value, at which time the valve 253 will open. When the valve opens, the motor outlet line 144 is connected to the motor inlet line 147 to thereby return fluid to the motor inlets. The valve 253 thus functions to regulate braking pressure and to provide a braking circuit

and to maintain the braking circuit charged with fluid. The braking relief valve **254** functions in a similar manner when the truck tends to roll rearwardly and the propelling motors thus tend to pump out the conduit **147** and to draw through the conduit **144**.

The setting on the braking relief valves **253** and **254** is high enough that these valves do not relieve system pressure when propelling. In a system wherein the constant system pressure maintained by the pump is about 1500 p.s.i., for example, the setting on the valve may be about 1600 p.s.i., for example. Thus, when the directional valve **18** is open, during propelling, the control valve **50** maintains the system pressure at 1500 p.s.i., and the braking relief valves **253** and **254** never open. When the directional valve **18** is positioned in neutral and valves **253** and **254** control braking, the constant pressure control valve **50** does not regulate pressure in the braking circuit. Instead, valves **253** and **254** control, and maintain pressure on the braking circuit.

If, during a braking operation, the propelling motors, while pumping, develop an excessively high pressure in the motor return line, over pressure relief valve means **27** is provided to relieve such pressures and maintain the same within safe limits. As illustrated, the over pressure relief valve means comprises a valve body **255** having an inlet **256** connected with the motor conduit **147** and an inlet **257** connected with the motor conduit **144**. A spring pressed check valve **258** normally maintains the inlet **256** closed. A spring pressed check valve **259** normally maintains the inlet **257** closed. Both inlets **256** and **257** communicate with a spring biased over pressure relief valve **260** which is normally positioned by its biasing means to prevent the flow of fluid from the valve body to drain line **169**.

In operation, if the operating condition is such that braking pressure is developed in the line **144** and increases to a predetermined excessively high value, say 1800 p.s.i., for example, in the circuit illustrated, valves **259** and **260** will be opened to relieve the braking pressure to drain line **169**. Similarly, if an excessively high braking pressure develops in conduit **147**, the check valve **258** and the relief valve **260** will open to relieve such pressure. When the pressure drops to a safe limit, these valves will close again. While the over pressure relief valve means has been illustrated as connected across the motor conduits **144** and **147**, with check valves to regulate the flow to the relief valve, it will be apreciated that the desired function may be obtained by providing separate over pressure relief valves in each of the lines **144** and **147**.

When the valve stem **153** of the directional valve **18** is positioned in neutral as illustrated in Fig. 1, under certain conditions, fluid lost from the braking circuit could be made up by leakage past the various valves to keep the braking circuit charged with fluid. Under other conditions, however, leakage past the valves may not be sufficient to maintain the braking circuit charged. Accordingly, means is provided to positively insure that the braking circuit is fully charged with fluid under all conditions to insure full braking.

The means to provide makeup fluid for the braking circuit includes the makeup valve means **28** previously referred to in general. When the valve stem **153** is positioned in neutral, fluid is supplied from the pump to the makeup valve through the pump delivery conduit **21**, a passage **261** through the valve stem **153**, and a conduit **262** which leads to a makeup valve inlet port **263**. The makeup valve **28** includes a valve body **264** formed with the inlet port **263** and with outlet ports **265** and **266**. The outlet port **266** connects with a conduit **267** having a check valve **268** normally biased to a closed position preventing the flow of fluid to the motor port **140**. The valve outlet port **265** connects with the conduit **269** having a check valve **270** normally biased to a closed position blocking the flow of fluid to the motor port **139**.

A valve member **271**, slidable in the makeup valve body **264** is formed with a passage **272** therethrough adapted to connect the valve inlet port **263** to the valve outlet ports **265** and **266**. So long as the braking circuit is charged adequately with braking fluid, the pressure of fluid in the conduits **267** and **269** is sufficient to hold the valve member **271** in the position illustrated in Fig. 1, blocking communication between the makeup valve inlet and outlet ports.

However, the makeup fluid from the pump is always available at the valve inlet port **263** when the valve stem **153** is positioned in neutral. Thus, in the event the braking circuit requires additional fluid, the pressure drop in the motor inlet line **147** or **144**, depending on the direction of rotation of the motors, will drop permitting the check valve **270** or **268** to open, permitting a drop in the pressure in the conduit **269** or **267**. In this event, a spring **274** forces the makeup valve member **271** to the left from the position illustrated in Fig. 1, to a position in which the stem passage **272** connects the inlet port **263** and the outlet ports **265** and **266**. Makeup fluid thereupon flows to the motor inlet conduit **147** or **144**. The pressure of fluid in the motor outlet conduit will maintain one of the check valves **270** or **268** closed, depending on the direction of rotation. When the demand for makeup fluid is satisfied, the pressure of fluid on the left end of the valve member **271** will return the valve member to the position illustrated in Fig. 1.

The automatic braking valve means **29** includes means forming a valve bore **281** having an inlet port **282** and an outlet port **283**. The inlet port **282** is connected with the conduit **284** which leads from the drain lines **168** and **169**. The outlet port **283** is connected by a conduit **285** to the drain line **129** which leads to the reservoir **16**. A valve member **287** is slidably disposed in the valve bore **281**, and is formed with a central reduced portion **288** which serves to connect the valve inlet port **282** and the valve outlet port **283** when the valve member is positioned as illustrated in Fig. 1. A spring **289** acts against the valve member **287**, biasing the valve toward a position in which communication is blocked between the inlet port **282** and the outlet port **283**. At the opposite end of the valve member from the spring **289**, the valve bore is provided with a pressure port **290** which is connected by a conduit **291** with a pressure port **292** in the valve body **135** of the directional valve **18**.

In operation, at any time when the pump **15** is pumping, and the directional valve **18** is open, the pressure of fluid in the conduits **21**, **167** and **291** is sufficient to maintain the valve member **287** in the position illustrated in Fig. 1, thereby placing the inlet port **282** and the outlet port **283** in communication. Thus, under normal operating conditions, when the propelling motors **10** and **11** are operated either forwardly or reversely, at either high speed or low speed, the return conduits from the motors are open to drain since the valve member **287** is positioned to connect the drain lines **284** and **285**. These conditions are illustrated in Figs. 3 and 4.

If, under these conditions the truck encounters a downward incline, the motors **10** and **11** may tend to overrun at a speed requiring more flow through the motors than is delivered by the pressure source. In this case, the motors begin to function as pumps, drawing fluid from the pressure conduit **21** and pumping to the drain lines **284** and **285**. Since the propelling motors are functioning as pumps and are requiring more fluid than that delivered by the pressure source, the pressure of fluid in the pressure conduit **291** drops, enabling the spring **289** to move the valve member **287** to the position illustrated in Fig. 10, blocking the flow of fluid from the conduit **284** to the conduit **285**. Since the flow of fluid from the motors **10** and **11** is thereby restricted, the motors are braked down to a proper speed, after which the pressure of the operating fluid will rise again to the proper value, again opening the braking valve **287**.

We claim:

1. In a hydraulic system, a pair of variable displacement hydraulic motors adapted for connection respectively with a pair of propelling wheels of a truck or the like, means providing a source of operating fluid at constant pressure, a directional valve for controlling the flow of pressure fluid from the source to the motors, means sensitive to a differential flow through the motors as a result of a differential resistance of the motors to turn, to increase the flow of pressure fluid to the motor having the greatest resistance and to decrease the flow of pressure fluid to the motor having the least resistance, fluid operable means for varying the displacement of the motors, valve and conduit means operable for connecting said displacement varying means alternatively to drain or to pressure fluid thereby to vary the displacement of the motors between a high speed, minimum torque value and a low speed, maximum torque value, and conduit means connected with the motor outlets for conducting fluid therefrom to drain including valve means operable to restrict the flow of fluid from the motors to thereby brake the motors.

2. In a hydraulic system, a pair of variable displacement hydraulic motors adapted for connection respectively with a pair of propelling wheels of a truck or the like, means providing a source of operating fluid at constant pressure, a directional valve movable between a neutral position blocking the flow of pressure fluid to the motors and an operative position connecting said source and the motors, valve means sensitive to a differential flow through the motors, as a result of a differential resistance of the motors to turn, to increase the flow of pressure fluid to the motor having the greatest resistance, and to decrease the flow of pressure fluid to the motor having the least resistance, fluid operable means for varying the displacement of the motors normally positioned to provide a high speed, minimum torque displacement, valve means normally positioned to connect said displacement varying means to drain and responsive to increased resistance of the motors to turn to connect said displacement varying means to pressure fluid to increase the displacement of the motors to a low speed, maximum torque value, valve means normally positioned to connect said displacement varying means to drain and manually operable to connect the displacement varying means to pressure fluid to increase the displacement of the motors to a low speed, maximum torque value, valving on said directional valve for restricting the flow of fluid from said motors when the directional valve is positioned in neutral to thereby brake the motors on slowdown and when the directional valve is positioned in neutral, and valve means subjected to pressure fluid from said source and thereby positioned to connect the motor outlets to drain, said last recited valve means being operable, upon a drop in the pressure of fluid from said source whenever the motors tend to overrun at a speed requiring more flow than that provided by the source, to restrict the flow from said motors to drain to thereby brake the motors.

3. In a hydraulic system, a pair of hydraulic motors adapted for connection respectively with a pair of propelling wheels of a truck or the like, means providing a source of operating fluid at constant pressure, a directional valve for controlling the flow of pressure fluid from the source to the motors, means sensitive to a differential flow through the motors, as a result of a differential resistance of the motors to turn, to increase the flow of pressure fluid to the motor having the greatest resistance and to decrease the flow of pressure fluid to the motor having the least resistance, and conduit means connected with the motor outlets for conducting fluid therefrom to drain including valve means operable to restrict the flow of fluid from the motors to thereby brake the motors.

4. In a hydraulic system, a variable displacement hydraulic motor adapted for connection with a propelling wheel of a truck or the like, means providing a source of operating fluid at constant pressure, a directional valve for controlling the flow of pressure fluid from the source to the motor, fluid operable means for varying the displacement of the motor normally biased toward a minimum displacement position, valve means normally positioned for connecting said displacement varying means to drain and responsive to increased resistance of the motor to turn to connect the displacement varying means to pressure fluid thereby to increase the displacement of the motor from a high speed, minimum torque value to a low speed, maximum torque value, and conduit means connected with the motor outlet for conducting fluid therefrom to drain including valve means operable to restrict the flow of fluid from the motor to thereby brake the motor.

5. In a hydraulic system, a pair of variable displacement hydraulic motors adapted for connection respectively with a pair of propelling wheels of a truck or the like, means providing a source of operating fluid at constant pressure, a directional valve for controlling the flow of pressure fluid from the source to the motors, means sensitive to a differential flow through the motors, as a result of a differential resistance of the motors to turn, to increase the flow of pressure fluid to the motor having the greatest resistance and to decrease the flow of pressure fluid to the motor having the least resistance, fluid operable means for varying the displacement of the motors, valve and conduit means operable for connecting said displacement varying means alternatively to drain or to pressure fluid thereby to vary the displacement of the motors between a high speed, minimum torque value and a low speed, maximum torque value.

6. In a hydraulic system, a variable displacement hydraulic motor adapted for connection with a propelling wheel of a vehicle, means providing a source of operating fluid under pressure, a pressure conduit for conducting pressure fluid from the source to the motor inlet, fluid operable means for varying the displacement of the motor, means normally biasing the displacement varying means to a minimum displacement position providing a high speed and low torque for the motor, torque valve means normally positioned to connect the displacement varying means to drain and responsive to increased resistance of the motor to turn to connect said displacement varying means to the pressure conduit to cause movement of the displacement varying means to increase the displacement of the motor to a low speed, high torque value.

7. In a hydraulic system, a variable displacement hydraulic motor adapted for connection with a propelling wheel of a vehicle, means providing a source of operating fluid under pressure, a pressure conduit for conducting pressure fluid from the source to the motor inlet, fluid operable means for varying the displacement of the motor, means normally biasing the displacement varying means to provide a high speed, low torque displacement, and torque valve means normally positioned to connect the displacement varying means to drain and manually operable to connect the displacement varying means to said pressure conduit to increase the displacement of the motor to a low speed, high torque value.

8. In a hydraulic system, a variable displacement hydraulic motor adapted for connection with a propelling wheel of a truck or the like, means providing a source of operating fluid under pressure, a pressure conduit for conducting pressure fluid from the source to the motor inlet, fluid operable means for varying the displacement of the motor, means normally biasing the displacement varying means to a minimum displacement position providing high speed and minimum torque for the motor, a valve normally positioned to connect the displacement varying means to drain and responsive to increased pressure in the conduit as a result of increased resistance

of the motor to turn to connect said displacement varying means to the pressure conduit to cause movement of the displacement varying means to a low speed, maximum torque position, and a second valve normally positioned to connect said displacement varying means to drain and manually operable to connect the displacement varying means to the pressure conduit to increase the displacement of the motor to a low speed maximum torque value.

9. In a hydraulic system, a variable displacement hydralic motor adapted for connection with a propelling wheel of a truck or the like, means providing a source of operating fluid at constant pressure, a directional valve having an inlet port connected to said source of pressure fluid, an outlet port connected to the motor inlet, and a valve member movable between a closed position blocking communication between said valve ports and an open position connecting said valve ports, fluid operable means for varying the displacement of said motor, means normally biasing said displacement varying means to a minimum displacement position providing high speed and low torque for the motor, a torque valve normally positioned to connect the displacement varying means to drain, and valve means incorporated in said directional valve for subjecting the torque valve to the pressure of fluid at the valve outlet port when the directional valve is open, said torque valve being responsive to an increase of pressure at the directional valve outlet due to increased resistance of the motor to turn to connect said displacement varying means to pressure fluid to increase the displacement of the motor to a low speed, maximum torque value.

10. In a hydraulic transmission, a reversible variable displacement hydraulic motor adapted for connection with a propelling wheel of a truck or the like, means providing a source of operating fluid at constant pressure, a directional valve having an inlet connected with the source of pressure fluid, a pair of motor ports connected respectively with the motor inlet and motor outlet, and a valve member having a neutral position blocking the inlet port and two operative positions in opposite directions from neutral respectively for connecting either motor port to the inlet port so that the motor may be operated forwardly or reversely, fluid operable means for varying the displacement of the motor, means normally biasing the displacement varying means to a minimum displacement position providing high speed and low torque for the motor, a torque valve normally positioned to connect the displacement varying means to drain, valve means incorporated in said directional valve for subjecting the torque valve to outlet pressure at the directional valve when the directional valve member is moved to either operative position, said torque valve being responsive to increases in outlet pressure at the directional valve and movable thereby to a position connecting said displacement varying means to pressure fluid to cause movement of the displacement varying means to a low speed, maximum torque position.

11. In a hydraulic system, a pair of hydraulic motors adapted for connection respectively with a pair of propelling wheels of a truck or the like, means providing a source of operating fluid under pressure, conduit means and selectively operable valve means connected with the source of pressure fluid and with the motors including a first main conduit and a first pair of branch conduits connecting the valve means to the motor inlets and a second main conduit and a second pair of branch conduits connecting the valve means to the motor outlets so that the motors may be operated forwardly or reversely, and control valve means positioned in one pair of said branch conduits sensitive to a differential resistance of said motors to turn to restrict the passage area of both branch conduits of said one pair equally thereby to decrease the flow through the motor having the least resistance and to increase the flow through the motor having the greatest resistance.

12. The combination as defined in claim 11, wherein said control valve means comprises: a valve body having a first port connected with one of said main conduits and second and third ports connected respectively with the pair of branch conduits associated with said one main conduit, valving for controlling flow from said first port to said second and third ports and from the second and third ports to the first port including a movable valve member normally positioned in a neutral center position enabling predetermined maximum equal flows in either direction through both motors, said movable valve member having opposite ends respectively sensitive to fluid pressure in said one pair of branch conduits and movable in response to a pressure differential in said one pair of branch conduits for equally restricting the passage areas connecting said first port to said second and third ports, whereby flow through the lightly loaded motor is restricted to a value substantially less than the capacity of said source, thereby enabling a substantial flow through the heavily loaded motor.

13. The combination as defined in claim 11, wherein said control valve means comprises: a valve body having a first port connected with one of said main conduits and having second and third ports connected respectively with the pair of said branch conduits associated with said one main conduit, a valve bore connecting said second and third ports, a pair of parallel flow divider passages both opening into said first port and into said valve bore, a valve member slidable in said valve bore, spring means normally biasing said valve member to a neutral center position placing said flow divider passages respectively in open communication with said second and third ports thereby to enable predetermined maximum equal flows through said motors in either direction, opposite ends of said valve member being exposed respectively to fluid in said one pair of branch conduits whereby a pressure differential in said one pair of branch conduits causes movement of the valve member to a position restricting the flows through said flow divider ports equally, thereby to reduce the flow through the lightly loaded motor to a value substantially less than the capacity of said source thereby to enable a substantial flow through said heavily loaded motor.

14. The combination as defined in claim 11, wherein said control valve means comprises: a valve body having a first port connected with one of said main conduits and having second and third ports connected respectively with the pair of said branch conduits associated with said main conduit, a valve bore connecting said second and third ports, a pair of flow divider passages both opening into said first port and into said valve bore, a valve member slidable in said valve bore, spring means normally biasing said valve member to a neutral center position respectively placing said flow divider passages in open communication with said second and third ports thereby to enable predetermined maximum equal flows through said motors in either direction, opposite ends of said valve member being exposed respectively to fluid in said one pair of branch conduits whereby a pressure differential in said one pair of branch conduits causes movement of the valve member to a position blocking flow through said flow divider passages, and a pair of by-pass passages respectively connecting said second and third ports to said first port, and manually adjustable valve means in said by-pass passages for restricting the flow through said lightly loaded motor to a flow substantially less than the capacity of said source, thereby leaving a substantial volume of fluid for the heavily loaded motor.

15. In a hydraulic system, a pair of hydraulic motors adapted for connection respectively with a pair of propelling wheels of a truck or the like, means providing a source of operating fluid under pressure, a directional valve having an inlet port connected with the source of

pressure fluid, a pair of outlet ports connected to drain, a pair of motor ports, and a movable valve member having a neutral position blocking communication of the inlet port with both motor ports and two operative positions respectively for connecting either motor port to the inlet port and the other motor port to a drain port, first conduit means including a main conduit and a pair of branch conduits connecting one motor port to the motor inlets and second conduit means including a main conduit and a pair of branch conduits connecting the other motor port to the motor outlets so that the motors may be operated forwardly or reversely, and control valve means positioned in one pair of said branch conduits sensitive to a differential resistance of said motors to turn to restrict the passage area of both branch conduits of said one pair equally thereby to decrease the flow through the motor having the least resistance and to increase the flow through the motor having the greatest resistance.

16. In a hydraulic system, a hydraulic motor adapted for connection with a propelling wheel of a vehicle, means providing a source of fluid under pressure, a pressure conduit connecting the source and the motor inlet, a directional valve in said pressure conduit movable from a neutral position blocking said pressure conduit to a non-blocking position permitting flow of pressure fluid to the motor, a return conduit connecting the motor outlet to drain, braking valve means in the return conduit operative to restrict the flow of fluid from the motor to drain when the directional valve is in neutral position thereby to brake the motor, a cross conduit connecting to the pressure conduit between the directional valve and the motor and connected to the return conduit between the motor and said braking valve means, a braking relief valve in said cross conduit normally biased to a closed position blocking the cross conduit to maintain braking pressure in the return conduit, said braking relief valve being subjected to pressure fluid in the return conduit and movable thereby upon a rise in braking pressure in the return line above a predetermined value to connect the return line and the pressure line thereby to bypass fluid to the motor inlet to regulate the braking pressure and maintain fluid in the braking circuit.

17. The combination defined in claim 16, including makeup valve means for supplying fluid from the pressure conduit ahead of the directional valve to the pressure conduit between the directional valve and the motor when the directional valve is positioned in neutral to thereby maintain the braking circuit charged with fluid.

18. The combination as defined in claim 17, wherein said makeup valve means comprises: a valve inlet communicating with the pressure conduit ahead of the directional valve, a valve outlet and a makeup conduit connecting the outlet to said pressure conduit between the directional valve and the motor, a movable valve member and means biasing the valve member toward a position connecting the valve inlet and the valve outlet, a check valve in said makeup conduit biased to closed position against the pressure at the valve outlet, the pressure of fluid in said makeup conduit between the valve outlet and the check valve urging said movable valve member toward a position blocking communication between the valve inlet and valve outlet, a drop in pressure in said pressure conduit between the directional valve and the motor when said directional valve is closed permitting said check valve to open thereby enabling movement of said valve member to a position connecting the pressure conduit ahead of the directional valve to the braking circuit.

19. The combination defined in claim 16, including an over-pressure relief valve connected to the return conduit and to drain, means normally biasing the over-pressure relief valve to a closed position blocking communication between the return conduit and drain, said over-pressure relief valve being subjected to pressure in the return conduit to open and connect the return conduit to drain upon an increase in braking pressure in the return conduit to a predetermined excessively high value.

20. The combination defined in claim 18, including makeup valve means for supplying fluid from the pressure conduit ahead of the directional valve to the pressure conduit between the directional valve and the motor when the directional valve is positioned in neutral to thereby maintain the braking circuit charged with fluid.

21. In a hydraulic system, a reversible hydraulic motor adapted for connection with a propelling wheel of a truck or the like, means providing a source of fluid at constant pressure, a directional valve having an inlet port connected with the source of pressure fluid, a pair of outlet ports connected to drain, a pair of motor ports, and a movable valve member having a neutral position blocking communication of the inlet port with both motor ports and two operative positions in opposite directions from neutral respectively for connecting either motor port to the inlet port and the other motor port to a drain port, a first conduit connecting one motor port to a motor inlet and a second conduit connecting the other motor port to the motor outlet so that the motor may be operated forwardly or reversely, and braking valve means operable to block the flow of fluid from the motor to drain thereby to brake the motor, comprising, a braking valve having an inlet port connected to the drain ports of said directional valve and an outlet port connected to drain, said braking valve including a braking valve member and means biasing the same toward a position blocking communication between the braking valve inlet and outlet ports, conduit means for subjecting the braking valve member to pressure fluid when the directional valve member is in either operative position thereby to position the braking valve member to connect the braking valve inlet and outlet ports, said biasing means being operable, upon a drop in the pressure of fluid in said pressure conduit whenever the motor tends to overrun at a speed requiring more flow than that provided by the source, to move said braking valve member to a position blocking the flow from said motor thereby to brake the motor.

22. In a hydraulic system, a hydraulic motor adapted for connection with a propelling wheel of a vehicle, a second hydraulic motor adapted for connection with auxiliary vehicle equipment, a variable displacement pump in fluid communication with the motors, selectively operable valve means for controlling the flow of operating fluid under pressure from the pump to the motors to selectively supply neither motor, either motor separately, or both motors simultaneously, a prime mover for driving the pump, means for varying the pump displacement to maintain pump outlet pressure constant regardless of whether the selectively operable valve means is positioned to supply neither motor, either motor or both motors, and means responsive directly to the volumetric flow rate in the pump outlet for varying the speed of the prime mover as the flow rate varies, comprising, a fuel feed device for regulating the flow of fuel to the prime mover, means biasing said fuel feed device to a normal idling position, a restrictive orifice positioned in the pump outlet, and means responsive to the pressure drop across the orifice for regulating said fuel feed device to increase the speed of the prime mover on increases in said pressure drop and to decrease the speed of the prime mover on decreases in said pressure drop.

23. In a hydraulic system, a hydraulic motor adapted for connection with a propelling wheel of a truck or the like, means providing a source of operating fluid at constant pressure, a pressure conduit connecting the source and the motor inlet, a directional valve in said pressure conduit movable from a neutral position blocking said conduit to a non-blocking position permitting flow of pressure fluid to the motor, a return conduit connecting the motor outlet to drain, valving on said directional valve positionable to block the motor return conduit when the directional valve is in neutral thereby to brake the

motor on slowdown and when the directional valve is in neutral, a valve member subjected to pressure fluid from said pressure conduit when said directional valve is in non-blocking position and thereby positioned to connect the motor outlet to drain, means biasing said valve member toward a position blocking the motor return conduit, said valve member being operable by said biasing means, upon a drop in pressure of fluid in said pressure conduit when said directional valve is in non-blocking position and the motor tends to overrun at a speed requiring more flow than that provided by the source, to restrict the flow from said motor thereby to brake the motor, a cross conduit connecting the pressure conduit and the return conduit at a point ahead of the braking valve means, and a braking relief valve in said cross conduit normally biased to a closed position blocking the cross conduit to maintain braking pressure in the return conduit, said braking relief valve being subjected to pressure fluid in the return conduit and movable thereby upon a rise in braking pressure in the return line above a predetermined value to connect the return line and the pressure line thereby to bypass fluid to the motor inlet to regulate the braking pressure and maintain fluid in the braking circuit.

24. The combination defined in claim 23, including an over-pressure relief valve connected to the return conduit and to drain, means normally biasing the over-pressure relief valve to a closed position blocking communication between the return conduit and drain, said over-pressure relief valve being subjected to pressure in the return conduit to open and connect the return conduit to drain upon an increase in braking pressure in the return conduit to a predetermined excessively high value.

25. The combination defined in claim 23, including makeup valve means for supplying fluid from the pressure conduit ahead of the directional valve to the pressure conduit between the directional valve and the motor when the directional valve is positioned in neutral to thereby maintain the braking circuit charged with fluid.

26. In a hydraulic system for mobile equipment, a hydraulic motor, means providing a source of fluid under pressure comprising a variable displacement pump, a variable speed prime mover for driving the pump, means for varying the pump displacement to meet varying demands of the motor, and means for sensing the flow rate between the pump and the motor and varying the speed of the prime mover as the flow rate varies, comprising, a fuel feed device for regulating the flow of fuel to the prime mover, means biasing said fuel feed device to a normal idling position, a restrictive orifice positioned in the pump discharge line, and means responsive to the pressure drop across said orifice for regulating said fuel feed device to increase the speed of the prime mover on increases in said pressure drop and to decrease the speed of the prime mover on decreases in said pressure drop.

27. In a hydraulic system, a hydraulic motor, a variable displacement pump having an outlet in fluid communication with the motor inlet, selectively operable valve means for controlling the flow of fluid from the pump to the motor, means for continuously maintaining fluid in the pump outlet at constant pressure regardless of the position of the selectively operable valve means including a control responsive to fluid pressure in the pump outlet for increasing pump displacement on decrease of pump outlet pressure and for decreasing pump displacement on increase of pump outlet pressure, a prime mover for driving the pump, and means responsive directly to the volumetric flow rate in the pump outlet for increasing the speed of the prime mover on increase of flow rate and for decreasing the speed of the prime mover on decrease of flow rate.

28. In a hydraulic system, a hydraulic motor, a variable displacement pump in fluid communication with the motor, fluid operable means for varying the pump displacement normally urged toward a minimum displacement position, selectively operable valve means controlling the flow of fluid from the pump to the motor, and valve means for continuously maintaining constant pressure at the pump outlet, comprising, a valve responsive to fluid pressure at the pump outlet for controlling the flow of pressure fluid to and from the displacement varying means to increase pump displacement on decrease of pump outlet pressure and to decrease pump displacement on increase of pump outlet pressure including a valve housing having a pressure port in fluid communication with the pump outlet, a drain port, and a control port in fluid communication with the displacement varying means, a valve member in the housing having one end exposed to the pressure port and a passage through the valve member connecting the opposite end thereof to the pressure port, and spring means acting in conjunction with fluid pressure at said opposite end of the valve member urging the valve member toward a position blocking communication between the control port and the drain port and placing the control port in communication with said valve member passage at said opposite end of the valve, to increase pump displacement, fluid pressure at said one end of the valve member urging the valve member toward a position blocking communication between the valve member passage and the control port and placing the control port in communication with the drain port, to decrease pump displacement.

29. Valve means for controlling the flow of pressure fluid to and from a pump displacement varying means, comprising, a valve housing having a pressure port, a drain port, and a control port, a valve member in the housing having one end exposed to the pressure port and a passage through the valve member connecting the opposite end thereof to the pressure port, and spring means, acting in conjunction with fluid pressure at said opposite end of the valve member urging the valve member to a position blocking communication between the control port and drain port and placing the control port in communication with said valve member passage at said opposite end of the valve member, fluid pressure at said one end of the valve member urging the valve member toward a position blocking communication between the valve member passage and the control port and placing the control port in communication with the drain port.

30. A control valve, comprising, a valve body having a first port connectable to a main conduit and having second and third ports connected respectively with a pair of branch conduits, a valve bore connecting said second and third ports, a pair of parallel flow divider passages both opening into said first port and into said valve bore, a valve member slidable in said valve bore, spring means normally biasing said valve member to a neutral center position placing said flow divider passages respectively in open communication with said second and third ports thereby to enable predetermined maximum equal flows through said second and third ports in either direction, opposite ends of said valve member being exposed respectively to fluid in said second and third ports whereby a pressure differential in said second and third ports causes movement of the valve member to a position restricting the flows through said flow divider ports equally.

31. A control valve, comprising, a valve body having a first port connectable with a main conduit and having second and third ports connectable respectively with a pair of branch conduits, a valve bore connecting said second and third ports, a pair of flow divider passages both opening into said first port and into said valve bore, a valve member slidable in said valve bore, spring means normally biasing said valve member to a neutral center position respectively placing said flow divider passages in open communication with said second and third ports thereby to enable predetermined maximum equal flows through said second and third ports in either direction, opposite ends of said valve member being exposed respectively to fluid in said second and third ports whereby

a pressure differential in said second and third ports causes movement of the valve member to a position blocking flow through said flow divider passages, and a pair of bypass passages respectively connecting said second and third ports to said first port, and manually adjustable valve means in said by-pass passages for restricting the flow therethrough.

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