April 10, 1951 W. FERRIS 2,548,146

HYDRAULIC TRANSMISSION, INCLUDING ONE PUMP AND A PLURALITY OF MOTORS

Filed April 3, 1947 4 Sheets-Sheet 1

FIG. 1

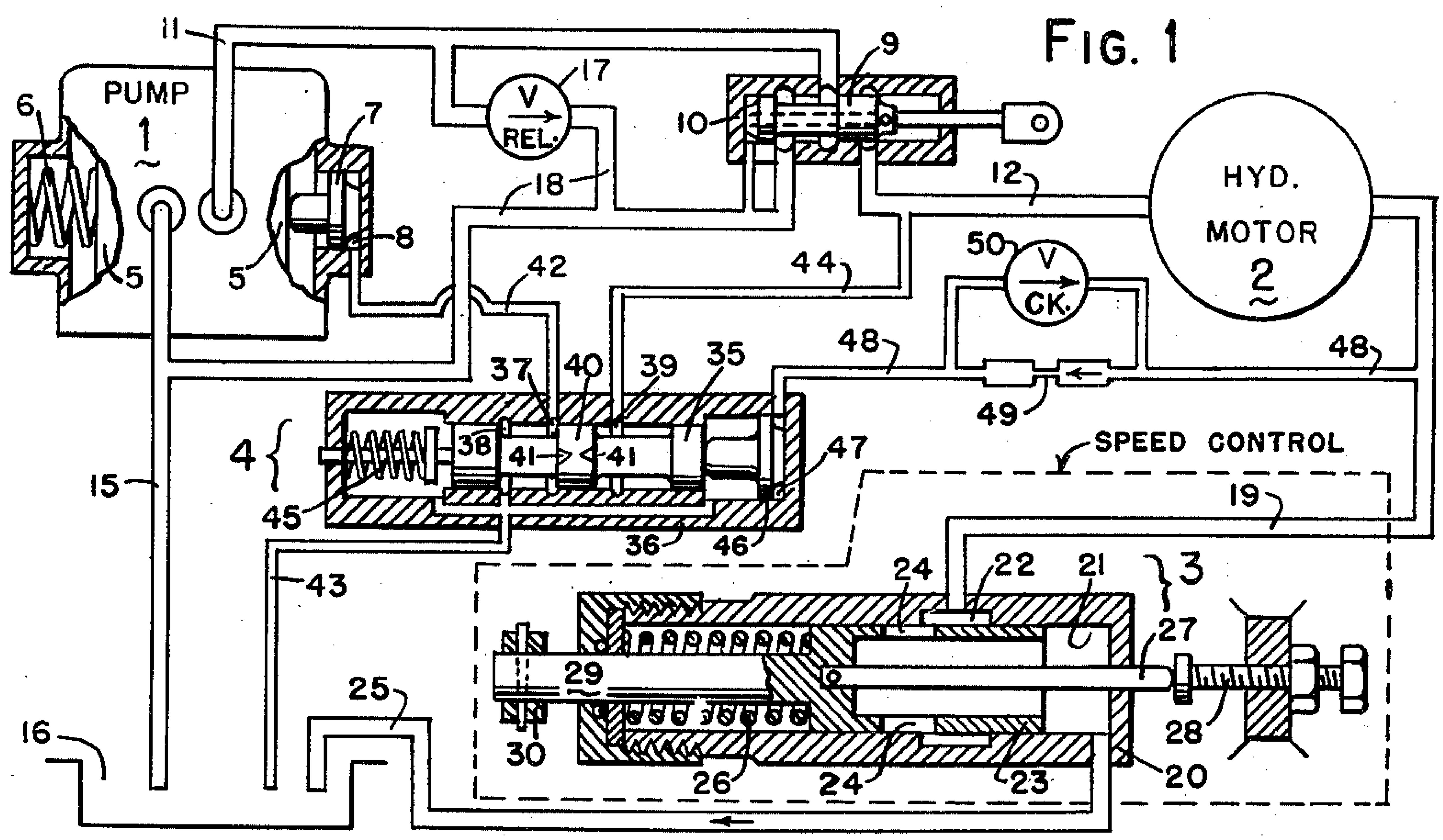

FIG. 2

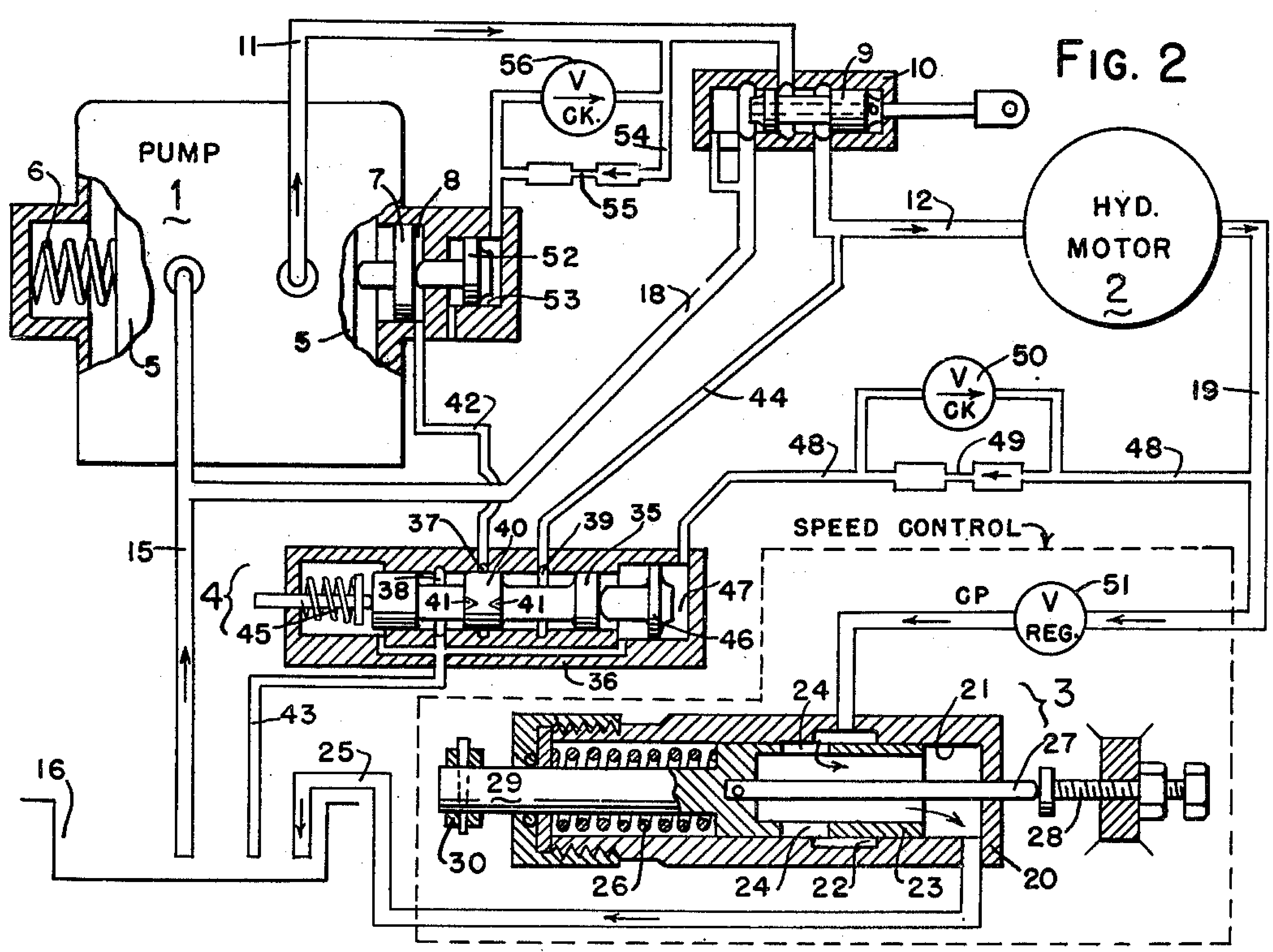

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FIG. 3

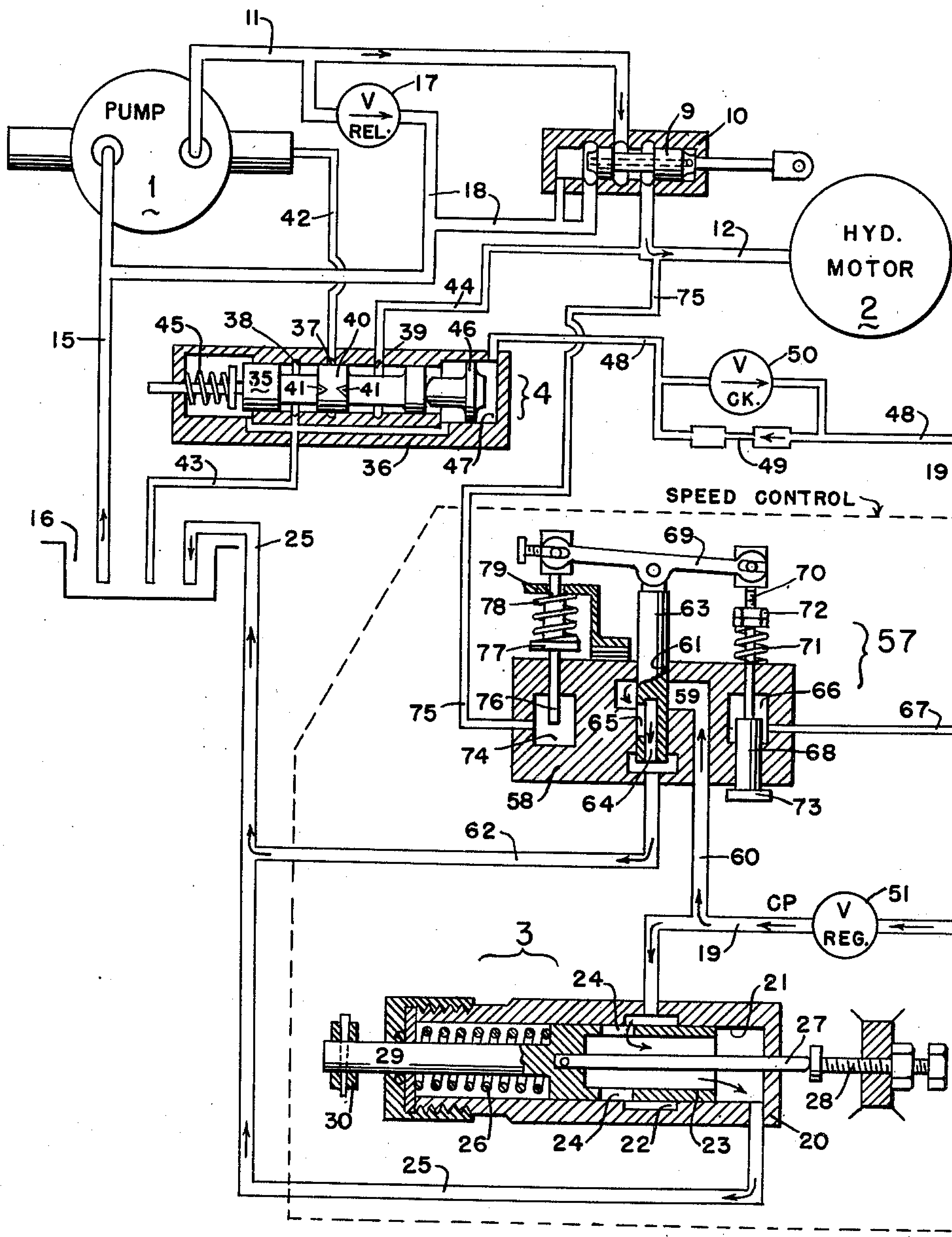

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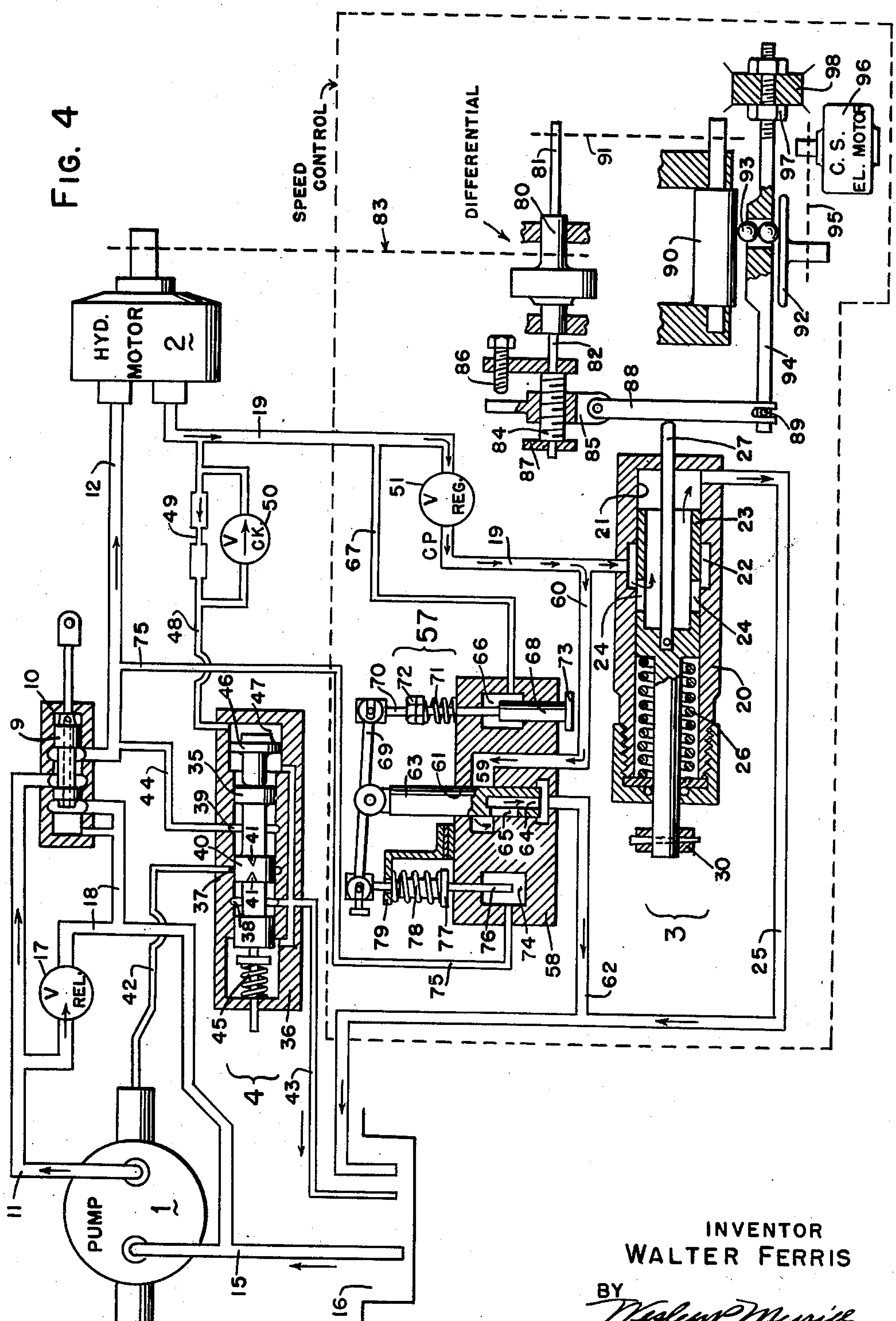
FIG. 4



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HYDRAULIC TRANSMISSION, INCLUDING ONE PUMP AND A PLURALITY OF MOTORS

Filed April 3, 1947

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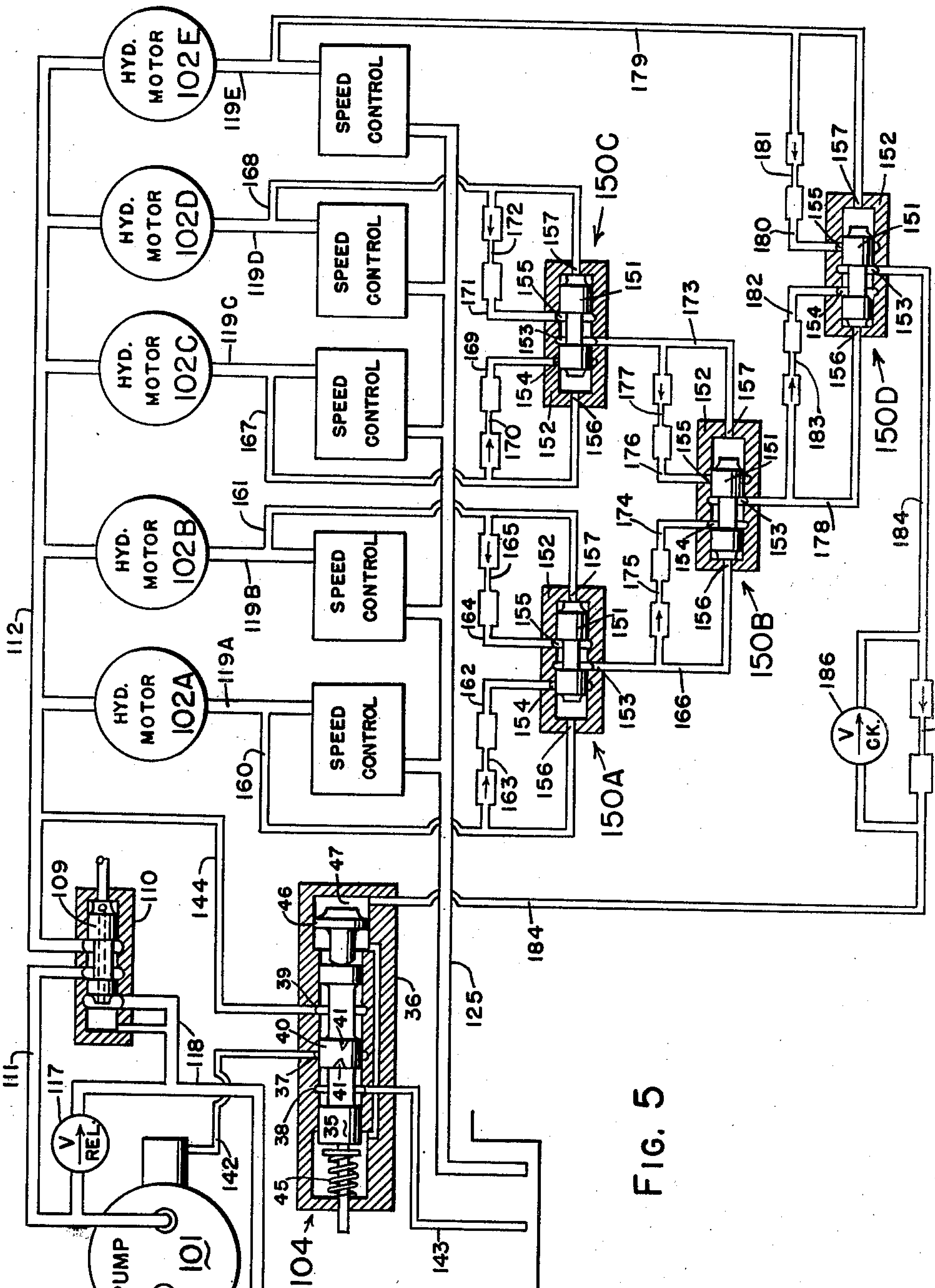

FIG. 5

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HYDRAULIC TRANSMISSION, INCLUDING ONE PUMP AND A PLURALITY OF MOTORS

Walter Ferris, Milwaukee, Wis., assignor to The Oilgear Company, Milwaukee, Wis., a corporation of Wisconsin

Application April 3, 1947, Serial No. 739,208

14 Claims. (Cl. 60—52)

This invention relates to hydraulic transmissions of the type in which a plurality of motors are energized by liquid supplied thereto from a pump to which the inlets of the motors are connected in parallel with each other and the speed of each motor is controlled by passing the outflow from each motor through a choke which imposes a back pressure on the motor so that the total load on each motor consists of the mechanical load thereon and the back pressure thereon.

In such a transmission, the pump must be capable of delivering liquid at a rate great enough to enable all of the motors to operate simultaneously at the maximum speeds which may be required but, if it delivers liquid at the rate when one or more of the motors are operating at a speed or speeds less than such maximum, the liquid discharged by the pump will exceed the liquid required to energize the motors and the excess liquid must be exhausted through a relief valve or an equivalent device which will result in loss of power and excessive heating of the liquid. Therefore, in order to obtain economical operation and to avoid excessive heating of the liquid, it is necessary to increase or decrease the rate at which the pump delivers liquid whenever the transmission is adjusted to increase or decrease the speed of one or more of the motors.

Pumps and motors when operating under load each have as an inherent characteristic thereof a "slip" which varies in response to variations in the drop in pressure across the pump or motor and which consists of a number of small factors. For example, the slip of a pump includes liquid which leaks out of the cylinders, liquid which leaks out of the pump valve, liquid which passes across the face of the pump valve from its high pressure port to its low pressure port and the compression of the liquid due to creating pressure therein.

If in a transmission of the above type no means were provided to compensate for variations in slip and if the pump were adjusted to deliver liquid at just the rate and pressure required to enable each of the motors to operate at the desired speed, the variation in slip resulting from a change in the mechanical load on any of the motors would make the rate of pump delivery either too little or too great to maintain the motors at the same speeds at which they were operating before the change in load occurred.

If the load driven by a motor of a transmis-

sion of the above type be increased or decreased after the motor speed has been determined by adjustment of the choke which throttles the outflow from the motor, and if no means be provided to compensate for variations in slip, then such change in load will cause the speed of that motor to vary from the desired speed.

The present invention has an an object to provide a hydraulic transmission in which a plurality of motors are energized by liquid supplied thereto from the same pump to which the motors are connected in parallel with each other, the speed of each motor is adjusted and controlled by throttling the outflow therefrom, the pump is automatically adjusted to deliver liquid at the rate required to cause the several motors to operate at their adjusted speeds and at the pressure required to enable the most heavily loaded motor to drive its load, and the speeds of the individual motors are maintained within closer limits than was heretofore possible in transmissions of this type.

Another object is to provide a transmission of the above type in which the pump is automatically adjusted to compensate for variations in slip in response to a variation in the load on any of the motors.

This is accomplished by passing the outflow from each motor through a "speed control," which throttles the flow therethrough to thereby control the speed of the motor, and by adjusting the displacement of the pump either in response to adjustment of the speed control or in response to variations in the speed of the motor which carries the heaviest load.

Each speed control may be simply a choke if some variation in motor speed is permissible or it may be more complicated if the motor speed is to be more accurately controlled.

The invention is exemplified by the transmissions shown schematically in the accompanying drawings in which the views are as follows:

Fig. 1 is a diagram of the hydraulic circuit of a transmission having a single motor and a speed control which consists of a single throttle valve, a means for adjusting the pump being illustrated and the parts being shown in the positions occupied when the transmission is idle.

Fig. 2 is a view similar to Fig. 1 but showing the pump provided with a control in addition to the control shown in Fig. 1 and showing the speed control as including a constant pressure valve in addition to the throttle valve, the parts being shown in the positions occupied when the transmission is operating.

Fig. 3 is a view similar to Fig. 2 but showing the speed control as including means to compensate for variations in the slip of the motor.

Fig. 4 is a view similar to Fig. 3 but showing a speed control which will maintain the motor speed proportional to a reference speed.

Fig. 5 is a diagram of the hydraulic circuit of a transmission in which the invention is embodied and in which the speed of each motor is controlled by a speed control which may be any one of the speed controls shown in Figs. 1–4.

The transmissions shown in Figs. 1–4 are not claimed herein but are claimed in a divisional application Serial No. 93,170, filed May 13, 1949.

Figure 1

The transmission shown in this figure includes a pump 1, a motor 2 which is energized by liquid delivered thereto by pump 1, a choke or throttle valve 3 which functions as a speed control for motor 2, and a control valve 4 which functions to effect adjustment of pump 1 until it is delivering liquid at the rate and pressure required to enable motor 2 to operate at the speed determined by the adjustment of throttle valve 3.

Pump 1 may be of any suitable type such as a radial piston pump, an axial pump, a vane pump or the like but it should have a control which is adjustable in response to variations in the pressure of the liquid discharged by motor 2.

For the purpose of illustration, pump 1 has been shown as being of the well known radial piston type and as having a displacement varying member or slideblock 5 which is constantly urged toward its maximum displacement position by a predetermined force such as by a spring 6. Pump 1 may be provided with a control including a piston 7 which is fitted in a stationary cylinder 8 and is adapted to move slideblock 5 toward its zero displacement position when liquid is supplied to cylinder 8 under the control of valve 4.

The transmission may be started and stopped by starting and stopping pump 1 but for the purpose of illustration it has been shown provided with a start and stop valve, having a valve 9 fitted in a cylinder 10 which is connected by a channel 11 to the outlet of pump 1 and is connected by a channel 12 to the inlet of motor 2.

Pump 1 is adapted to draw liquid through a channel 15 from a reservoir 16 and to discharge it into channel 11. The pressure created by pump 1 is limited by a relief valve 17 which in practice is arranged inside the pump casing but which has been shown as having its inlet connected to channel 11 and its outlet connected to a channel 18 which is connected to channel 15 and also to valve casing 10.

Motor 2 has its outlet connected by a channel 19 to the casing 20 of throttle valve 3. Casing 20 has an axial bore 21 and an annular groove or port 22 formed in the wall of bore 21 and communicating with channel 19. Port 22 is controlled by a hollow valve member or throttle 23 having one or more orifices 24 formed in its side wall and adapted to register with port 22 to a greater or lesser extent so that liquid may flow from channel 19 through port 22, orifices 24 and the interior of throttle 23 into the right end of bore 21 which is connected by a channel 25 to reservoir 16. Since motor 2 can discharge liquid only at the rate at which the discharged liquid can flow through orifices 24, throttle valve 3 constitutes a speed control for motor 2.

Throttle 23 is urged toward the right by a spring 26 and it is adapted to be moved toward the left by means of a rod 27 which is fixed to throttle 23 and extends through the right end of casing 20. Adjustment is made by moving rod 27 in one direction or the other. As shown, rod 27 engages an adjusting screw 28 which may be turned in one direction to move throttle valve 23 toward the left or may be turned in the opposite direction to permit spring 26 to move throttle 23 toward the right and thereby vary the effective area of orifices 24. Throttle 23 may be provided with a stem 29 which extends through the left end of casing 20 and carries a gage block 30 so that the distance between the edge of port 22 and the edges of orifices 24 may be determined by measuring the distance between block 30 and a fixed point such as the end of casing 20.

Control valve 4 has been shown as including a valve plunger 35 which is fitted in a valve casing 36 having three annular grooves or ports 37, 38 and 39 formed therein. Port 37 may be of substantial width and the central piston 40 on plunger 35 may be of the same width so that, when plunger 35 is in its central position, port 37 will be blocked but a very slight movement of plunger 35 in one direction or the other will open port 37 to one or the other of ports 38 and 39.

However, port 37 has been shown as being relatively narrow and piston 40 has been shown as having a plurality of tapered grooves 41 extending toward each other from opposite ends thereof and so located that, when valve plunger 35 is in its central position as shown in Fig. 2, port 37 will be substantially blocked, a slight movement of plunger 35 in one direction or the other from its central position will cause a slight flow of liquid to or from port 37 and a greater movement of plunger 35 will cause a greater flow.

Port 37 is connected to cylinder 8 by a channel 42, port 38 is connected to reservoir 16 by a channel 43 and port 39 is supplied with motive liquid in any suitable manner such as by being connected to channel 12 by a channel 44. The arrangement is such that, when valve plunger 35 is shifted toward the right from its central position, liquid may escape from cylinder 8 through channel 42, valve 4 and channel 43 to reservoir 16 and thereby permit spring 6 to move slideblock 5 toward the right to increase the displacement of pump 1 and, when pump 1 is delivering liquid to motor 2 and valve plunger 35 is shifted toward the left, liquid may flow from channel 12 through channel 44, valve 4 and channel 42 to cylinder 8 and cause piston 7 to shift slideblock 5 toward the left to decrease the displacement of pump 1.

Valve plunger 35 is urged toward the right by a spring 45 and it is adapted to be moved toward the left by a piston 46 fitted in a cylinder 47 which is arranged upon or formed in the right end of valve casing 36. The right end of cylinder 47 is connected to channel 19 by a channel 48 so that piston 46 is subjected to any pressure prevailing in channel 19. When the pressure in channel 19 rises to such a value that the force exerted by the liquid upon piston 46 exceeds the force exerted upon plunger 35 by spring 45, piston 46 will move plunger 35 toward the left, and when the pressure in channel 19 drops below that value, spring 45 will move plunger 35 toward the right.

If channel 48 were unrestricted, a sudden rise in pressure in channel 19 above the given value might cause liquid to flow so rapidly through channel 48 to cylinder 47 that piston 46 would move valve plunger 35 far enough to permit liquid to flow at a rapid rate from channel 12 into cylinder 8 and cause piston 7 to move slideblock 5 far enough toward the left to reduce pump displacement too much which would result in a drop in pressure which then would cause slideblock 5 to again move toward the right. Slideblock 5 might be shifted several times before it stopped in its correct position.

In order to avoid the possibility that slideblock 5 might oscillate or hunt, the flow from channel 19 to cylinder 47 is restricted such as by inserting a choke 49 in channel 48. However, it is desirable that the displacement of pump 1 be increased rapidly when necessary. Therefore, means are provided for permitting free flow from cylinder 47 to channel 19 such as by connecting a check valve 50 in parallel with choke 49.

Operation

When pump 1 is running and valve 9 is in the position shown in Fig. 1, pump 1 will be at its maximum displacement and will draw liquid through channel 15 from reservoir 16 and discharge it into channel 11. The liquid discharged by pump 1 will flow through channel 11, valve casing 10 and channels 18 and 15 back to the inlet of pump 1. Valve plunger 35 of control valve 4 will be held by spring 45 at the limit of its movement toward the right due to the lack of any pressure in channel 19.

When valve 9 is shifted to the position shown in Fig. 2, the liquid discharged by pump 1 will flow through channel 11, valve casing 10 and channel 12 to motor 2 and cause it to start to operate and to discharge liquid through channel 19, throttle valve 3 and channel 25 to reservoir 16. Since motor 2 cannot instantly accelerate its load to full speed, the displacement of pump 1 will remain at maximum, pump 1 will continue to discharge liquid at its full volumetric rate and pump pressure will rise to maximum and open relief valve 17 so that the liquid discharged by pump 1 in excess of the liquid required by motor 2 may flow through relief valve 17 and channels 18 and 15 back to the inlet of the pump.

Motor 2 will gradually accelerate and it will discharge liquid at a gradually increasing rate through channel 19, throttle valve 3 and channel 25 to reservoir 16. Throttle valve 3 will at first offer but little resistance to the flow of liquid therethrough but its resistance will gradually increase as the flow therethrough increases and this increasing resistance will impose upon motor 2 a back pressure which gradually increases and which extends from channel 19 through channel 48 and acts upon piston 46.

Orifices 24 are so proportioned that, at any adjusted motor speed, the entire discharge from motor 2 will flow through throttle valve 3 at a predetermined low back pressure, such as 25 p. s. i., in channel 19. This low back pressure is sufficient to cause piston 46 to move plunger 35 of control valve 4 into its neutral position as shown in Fig. 2. Therefore, when motor 2 reaches its adjusted speed as determined by the adjustment of throttle valve 3, the back pressure in channel 19 will be at the predetermined value, such as 25 p. s. i., and control valve plunger 35 will be in its neutral position.

Since at this time pump 1 is still discharging liquid at its maximum rate, motor 2 will start to run faster than its adjusted speed and to discharge liquid at a rate in excess of the rate at which liquid can flow through throttle valve 3 at the predetermined back pressure, thereby causing the back pressure to increase and enable piston 46 to move valve plunger 35 far enough to open port 37 to port 39. Then liquid will flow from channel 12 through channel 44, valve 4 and channel 42 to cylinder 8 and cause piston 7 to shift slideblock 5 toward the left until pump 1 is delivering only enough liquid to maintain a pressure which exceeds the pressure required by motor 2 to drive its load only by the small amount, such as 25 p. s. i. required to enable piston 46 to shift valve plunger 35 against the resistance of spring 45.

When the pressure drop across the motor is subtracted from the reduced input pressure in channel 12, the resulting back pressure in channel 19 is reduced by the same amount until the predetermined value of say 25 p. s. i. is reached. At this point spring 45 overcomes the back pressure acting on piston 46 and moves valve plunger 35 toward the right until port 37 is open to port 39 only enough to enable the pressure in channels 12 and 44 to maintain in cylinder 8 just enough pressure to enable piston 7 to hold slideblock 5 in its adjusted position against the thrust of spring 6.

Thereafter, if the speed of motor 2 should tend to increase above the speed determined by the adjustment of throttle valve 3, motor 2 would tend to discharge liquid at an increased rate but this tendency would be resisted by throttle valve 3 which will cause the back pressure to rise and shift piston 46 and valve plunger 35 toward the left to effect a reduction in the displacement of pump 1 and thereby overcome the tendency of motor 2 to increase its speed.

Conversely, if the speed of motor 2 should tend to decrease below the speed determined by the adjustment of throttle valve 3, motor 2 would tend to discharge liquid at a reduced rate which would cause the back pressure to drop and permit spring 45 to move valve plunger 35 toward the right to effect an increase in the displacement of pump 1 and thereby overcome the tendency of motor 2 to decrease its speed.

Pump 1 thus delivers only enough liquid to enable motor 2 to operate at the speed determined by the adjustment of throttle valve 3 and it creates only enough pressure to enable motor 2 to drive its load and to enable piston 46 to shift valve plunger 35, thereby avoiding the waste of power and the heating of liquid which is inherent in the prior transmissions in which motor speed is controlled by throttling motor outflow.

Since the flow through an orifice varies with the drop in pressure thereacross, the speed of motor 2 will vary somewhat from the speed determined by the adjustment of throttle valve 3 but the speed of motor 2 will be maintained within a narrow enough range for many installations. If it is desired to maintain the speed of motor 2 within a narrower range, a constant pressure valve may be inserted into channel 19, as indicated at 51 in Fig. 2, to maintain a substantially constant pressure at the inlet of throttle valve 3.

Figure 2

In this figure, the transmission has been shown provided with two pump controls instead of one. One of the controls includes a piston 7 fitted in a cylinder 8 and a valve to control the flow of liquid to and from cylinder 8 the same as in Fig. 1.

The other control is of the type which permits the pump to discharge liquid at its full volumetric rate until pump pressure reaches a given maximum and then it reduces pump displacement until the pump is delivering just enough liquid to maintain that maximum pressure constant. This control may be of any suitable type, such as that shown in Patent No. 2,080,810, but for the purpose of illustration it has been indicated schematically as having a piston 52 fitted in a cylinder 53 which is connected to channel 11 by a channel 54 having a choke 55 inserted therein to limit the rate of flow from channel 11 to cylinder 53, a check valve 56 being connected in parallel with choke 55 to permit free flow from cylinder 53 to channel 11. A relief valve is built into the pump or into the control according to common practice but the relief valve has been omitted from the drawing in order to avoid complicating the view.

Servo motor 52—53 has been shown arranged outward from servo-motor 7—8 with the stem of its piston 52 adapted to engage piston 7 which has its stem in contact with slideblock 5 but the positions of the two servo-motors may be reversed.

Also, a constant pressure valve 51 is arranged in channel 19 to maintain a substantially constant pressure at the inlet of throttle valve 3. Since motor 2 can discharge liquid only at the rate at which the discharged liquid can flow through the orifices 24 of throttle valve 3 and since valve 51 maintains a substantially constant pressure at the inlet of throttle valve 3 so that the drop in pressure across orifices 24 is substantially constant, throttle valve 3 and constant pressure valve 51 constitute a speed control for motor 2.

The transmission is otherwise the same as shown in Fig. 1. Therefore, like parts have been indicated by like reference numerals and further description thereof will not be given.

When the transmission is started and pump pressure rises to maximum, liquid will flow from channel 11 through channel 54 to cylinder 53 and cause piston 52 to shift slideblock 5 toward the left and thereby reduce pump displacement until pump 1 is delivering just enough liquid to maintain that maximum pressure constant. Thereafter, the transmission will function in the previously described manner. However, valve 51 will maintain a substantially constant pressure at the inlet of throttle valve 3 and, when motor 2 tends to accelerate beyond the speed determined by the adjustment of throttle valve 3, constant pressure valve 51 will cause the back pressure in channel 19 to rise very abruptly and promptly effect a reduction in pump displacement which is just sufficient to overcome the tendency of motor 2 to accelerate. The speed of motor 2 is thus maintained within closer limits than would be possible if valve 51 were omitted.

Figure 3

In this figure, the transmission has been shown provided with means to compensate for variations in the slip of the motor due to variations in motor load. The pump may be provided with a single control as shown in Fig. 1 or it may be provided with two controls as shown in Fig. 2. Since the transmission is otherwise unchanged, like parts have been indicated by like reference numerals and further description thereof will not be given.

When a motor is operating under load, liquid will pass across the face of the motor valve from the inlet port to the outlet port thereof and will

augment the volume of liquid discharged from the motor cylinders, and the liquid discharged from the motor cylinders will expand into a greater volume due to the drop in pressure across the motor. The liquid which passes across the face of the motor valve and the expansion of the liquid discharged from the motor cylinder causes the motor during each revolution thereof to discharge a volume of liquid in excess of the volume of high pressure liquid contained in its cylinders, that is the liquid actually used in driving the motor, and this excess liquid will be referred to herein as the "slip" of the motor.

Compensation for variations in motor slip may be made by varying the effective area of orifices 24 in throttle valve 3 in response to variations in the drop in pressure across the motor but the transmission has been shown provided with a separate choke or slip compensator 57 which is connected in parallel with throttle valve 3 and is adjusted in response to variations in the drop in pressure across the motor.

The slip compensator may take various forms but for the purpose of illustration it has been shown as including a body 58 having an inlet chamber 59 formed therein and connected by a channel 60 to channel 19 at a point between throttle valve 3 and constant pressure valve 51. Chamber 59 intersects a bore 61 which is formed in body 58 and communicates at its lower end with a discharge channel 62 shown as being connected to discharge channel 25. A throttle 63 is closely fitted in bore 61 and has an axial bore 64 extending inward from its lower end into communication with one or more orifices 65 formed in the wall of bore 64 and adapted to register to a greater or lesser extent with chamber 59 when the slip compensator is functioning.

Body 58 also has provided therein a back pressure chamber 66 which is connected to the outlet of the motor to be controlled such as by being connected by a channel 67 to channel 19 at a point between motor 2 and constant pressure valve 51. A plunger 68 is closely fitted in the lower part of body 58 and extends into chamber 66 so that its upper end is subjected to any pressure prevailing in chamber 66. Plunger 68 is adapted to transmit motion to a lever 69 which is pivoted intermediate its ends upon the upper end of throttle 63. Preferably, one end of lever 69 is connected to the lower end of plunger 68 by a yoke which extends around body 58 but for the purpose of illustration plunger 68 has been shown as being connected to one end of lever 69 by a rod 70 formed integral with plunger 68 and as being urged upward by a spring 71 which encircles rod 70 between the top of body 58 and adjusting nuts 72 which are threaded upon rod 70, upward movement of plunger 68 being limited by a stop 73 arranged upon its lower end.

Body 58 also has formed therein a high pressure chamber 74 which is connected to the inlet of the motor to be controlled such as by being connected to channel 12 by a channel 75. Closely fitted in the upper part of body 58 is a plunger 76 which extends into chamber 74 and is connected at its upper end to the other end of lever 69. Plunger 76 has a stop 77 fixed to or formed upon the intermediate portion thereof and it is urged downward by a spring 78 arranged between stop 77 and an abutment 79 which is fastened to body 58.

The arrangement is such that the pressure prevailing at the inlet of the motor tends to move plunger 76 upward and the pressure prevailing at the outlet of the motor tends to move plunger 68 downward. When the inlet pressure exceeds the value determined by the adjustment of spring 78, the liquid in chamber 74 will move plunger 76 upward and compress spring 78 until the force exerted by spring 78 equals the force exerted by the liquid upon the lower end of plunger 76. When the outlet pressure exceeds the value determined by the adjustment of spring 71, the liquid in chamber 66 will move plunger 68 downward and compress spring 71 until the force exerted by spring 71 equals the force exerted by the liquid upon the upper end of plunger 68.

Upward movement of either one of the two plungers 68 and 76 without a corresponding downward movement of the other one of the two plungers will cause lever 69 to raise throttle 63 and thereby increase the effective area of orifices 65. That is, a greater area of orifices 65 will register with chamber 59. Conversely, downward movement of either one of the two plungers 68 and 76 without a corresponding upward movement of the other one of the two plungers will cause lever 69 to lower throttle 63 and thereby decrease the effective area of orifices 65.

When the motor is driving a substantial load, the inlet pressure will be high enough to have raised plunger 76 part way to the limit of its movement, the back pressure or outlet pressure will be high enough to have moved plunger 68 downward a short distance and the relative positions of the two plungers will be such that lever 69 will have raised throttle 63 to uncover a part of the area of orifices 65. If springs 71 and 78 are properly calibrated, the positions of plungers 68 and 76 will be such that the effective area of orifices 65 will be just large enough to permit liquid to flow therethrough at a rate approximately equal to the slip of the motor. Thereafter, a variation in the load upon the motor will cause a variation in the drop in pressure across the motor which will cause plunger 76 and/or plunger 68 to readjust throttle 63 in accordance with the variation in motor slip due to the variation in motor load. Throttle valve 3, constant pressure valve 51 and slip compensator 57 thus constitute a speed control for motor 2.

The transmission will function in the previously described manner except that a part of the liquid discharged by motor 2 will flow through slip compensator 57 and the rate of flow through compensator 57 will be varied proportionally to variations in pressure drop across the motor to compensate for the variations in motor slip.

Figure 4

In this figure, throttle valve 3 has been shown as being adjusted in response to the speed of motor 2 varying relatively to a reference speed instead of having only a manual adjustment as shown in Figs. 1, 2 and 3. Since the transmission is otherwise unchanged from the form shown in Fig. 3, like parts have been indicated by like reference numerals and further description thereof will not be given.

As shown, the speed of motor 2 is compared with a reference speed through a differential having three legs 80, 81 and 82. The differential has its first leg 80 driven by motor 2 at a speed proportional to the speed thereof as by means of a suitable drive 83 and its second leg 81 driven at a reference speed so that its third leg 82 rotates in one direction or the other in response to the motor speed varying relatively to the reference speed.

Throttle valve 3 is adjustable in any suitable manner in response to rotation of leg 82. As shown, leg 82 is adapted to rotate a screw 84 having a nut 85 threaded thereon and restrained from rotation in any suitable manner so that rotation of screw 84 in one direction or the other will cause nut 85 to move axially in one direction or the other, axial movement of nut 85 being limited by two stops 86 and 87. Adjustment of throttle valve 3 in response to movement of nut 85 is effected by means of a lever 88 which engages the control rod 27 of throttle valve 3 and has one of its ends pivoted to nut 85 and its other end pivoted upon a normally stationary pin 89.

In order that the motor speed may be adjusted, means may be provided to regulate the speed at which leg 81 of the differential is driven. As shown, leg 81 is driven from a power source through a friction transmission having a cylinder 90 which is connected to leg 81 by a suitable drive 91, a friction disk 92 which is driven at a reference speed, two balls 93 which transmit motion from disk 92 to cylinder 90, and an adjusting member 94 which retains balls 93 in adjusted positions and also carries the pin 89 upon which lever 88 is pivoted.

Disk 92 may be driven at any desired speed which may be constant or varied. As shown, disk 92 is driven through a suitable drive 95 from a constant speed electric motor 96. Adjusting means 94 may be moved to and held in adjusted position in any suitable manner but for the purpose of illustration it has been shown as being adjusted by means of a nut 97 which is threaded upon one end portion of member 94 and is held against a stationary abutment 98 by the thrust of the spring 26 in throttle valve 3.

The arrangement is such that, if balls 93 were on the axis of disk 92, no motion would be transmitted from disk 92 to cylinder 90 but, when disk 92 is rotated and balls 93 are offset from the axis of disk 92, cylinder 90 will be driven through balls 93 from disk 92 and it will drive leg 81 of the differential through drive 91 at a speed determined by the distance balls 93 are offset from the axis of disk 92.

The transmission will operate in the previously described manner except that a variation in the speed of motor 2 relative to the reference speed will cause the differential to adjust throttle valve 3 which will vary the resistance to the discharge of liquid by motor 2 and thereby correct the variation in motor speed.

More specifically, an increase in motor speed above the correct speed as determined by the adjustment of member 94 will cause drive 83 to increase the speed of leg 80 of the differential relatively to the speed of leg 81 and thereby cause leg 82 to rotate. Leg 82 will rotate screw 84 which will move nut 85 and the upper end of lever 88 toward the left. Lever 88 through rod 27 will move throttle 23 toward the left to decrease the effective area of orifices 24 and thereby reduce the motor speed until motor 2 is operating at the correct speed. Conversely, a decrease in motor speed below the correct speed as determined by the adjustment of member 94 will cause drive 83 to decrease the speed of leg 80 of the differential relatively to the speed of leg 81 and thereby cause leg 82 to rotate. Leg 82 will rotate screw 84 which will move nut 85 and the upper end of lever 88 toward the right. Moving lever 88 toward the right will permit spring 26 to move throttle 23 toward the right to increase the effective area of orifices 24 and thereby permit the motor speed to increase until motor 2 is operating at the correct speed.

Throttle valve 3, slip compensator 57, constant pressure valve 51 and the differential thus constitute a speed control which maintains the speed of motor 2 proportional to a reference speed. However, if motor 2 is to operate only at a given speed which may be either constant or varying, friction transmission 90—94 and its drive 95—96 may be omitted, pin 89 may be fixed in a stationary position and leg 81 of the differential may be driven at a given speed which may be constant or varying.

Also, slip compensator 57 may be omitted as the differential will adjust throttle valve 3 to compensate for variations in motor slip due to variations in motor load but a slight interval of time is required for the differential to make such correction while slip compensator 57 responds substantially instantaneously to make the correction. Therefore, the slip compensator should be incorporated in the speed control when prompt response is desired.

At the same time that the speed control is causing motor 2 to operate at the correct speed, any variation in the back pressure on motor 2 causes control valve 4 to effect adjustment of pump displacement to cause pump 1 to deliver liquid at a correct rate to enable motor 2 to operate at the speed determined by the speed control and at the correct pressure to enable motor 2 to drive its load as previously explained.

Figure 5

The transmission shown in this figure includes a plurality of hydraulic motors, a single pump for energizing all of the motors, a speed control for each of the motors and means for adjusting pump displacement in response to variations in the back pressure on the motor having the lowest back pressure.

As shown, a pump 101 supplies all of the liquid for energizing a plurality of motors 102, five being shown and designated 102A, 102B, 102C, 102D and 102E. Pump 101 may be of any suitable type and it may have its displacement varied solely in response to variations in motor back pressure as shown in Fig. 1 or it may have its displacement initially reduced in response to pump pressure reaching a given maximum and thereafter have its displacement varied in response to variations in motor back pressure as shown in Fig. 2.

The transmission may be started and stopped by starting and stopping pump 101 but for the purpose of illustration it has been shown provided with a start and stop valve having a valve 109 fitted in a cylinder 110 which is connected by a channel 111 to the outlet of pump 101 and is connected by a channel 112 to the inlets of all of the motors 102.

Pump 101 is adapted to draw liquid through a channel 115 from a reservoir 116 and to discharge it into channel 111. The pressure created by pump 101 is limited by a relief valve 117 which in practice is arranged inside the pump casing but which has been shown as having its inlet connected to channel 111 and its outlet connected to a channel 118 which is connected to channel 115 and also to valve casing 110.

Each motor 102 has its outlet connected by a channel 119 to a speed control which controls the speed of that motor, the channels being designated 119A, 119B, 119C, 119D and 119E and connected to motors 102A, 102B, 102C, 102D and 102E respectively. Each of the speed controls may be any one of the speed controls shown in Figs. 1, 2, 3 and 4 or be a speed control such as shown in Fig. 4 but with the friction transmission and/or the slip compensator omitted therefrom. All of the liquid discharged by each motor 102 flows through its speed control into a channel 125 which is connected to all of the speed controls and discharges into reservoir 116.

Adjustment of pump displacement in response to variations in motor back pressure is under the control of a valve 104 which is identical to the valve 4 previously described and corresponding parts thereof have been indicated by corresponding reference numerals so that further description thereof is unnecessary. Control valve 104 is connected into the circuit in the same manner as the control valve 4 previously described. That is, it has its port 37 connected to the displacement varying means of pump 101 by a channel 152, its port 38 communicates with a channel 143 which discharges into reservoir 116 and its port 39 is connected to channel 112 by a channel 144.

Also, control valve 104 functions in the same manner that control valve 4 functions as previously explained. That is, an increase in the pressure in cylinder 47 causes piston 46 to move valve plunger 35 toward the left to permit liquid to flow from channel 112 through channel 144, valve 104 and channel 142 to the pump displacement varying means and thereby effect a decrease in pump displacement, and a decrease in the pressure in cylinder 47 permits spring 45 to move valve plunger 35 toward the right to permit liquid to flow from the displacement varying means 142, its port 38 communicates with a channel 143 to reservoir 116 and thereby effect an increase in pump displacement.

In order that valve 104 may be operated in response to variations in the back pressure on the motor having the lowest back pressure, the transmission is provided with one or more selector valves 150. The number of selector valves required is one less than the number of motors so that only one selector valve would be required if the transmission had only two motors. As shown, the transmission is provided with four selector valves which are designated 150A, 150B, 150C and 150D respectively, and each valve has a plunger 151 fitted in a valve body 152 having three annular grooves or ports 153, 154 and 155 formed in its side wall and two ports 156 and 157 formed in its opposite ends.

Valve 150A has its port 156 connected to channel 119A by a channel 160, its port 157 connected to channel 119B by a channel 161, its port 154 connected to channel 160 by a channel 162 having a choke 163 arranged therein, its port 155 connected to channel 161 by a channel 164 having a choke 165 arranged therein and its port 153 connected to the port 156 of valve 150B by a channel 166.

Valve 150C has its port 156 connected to channel 119C by a channel 167, its port 157 connected to channel 119D by a channel 168, its port 154 connected to channel 167 by a channel 169 having a choke 170 arranged therein, its port 155 connected to channel 168 by a channel 171 having a choke 172 arranged therein, and its port 153 connected to port 157 of valve 150B by a channel 173.

Valve 150B has its port 154 connected to channel 166 by a channel 174 having a choke 175 arranged therein, its port 155 connected to channel 173 by a channel 176 having a choke 177 arranged therein, and its port 153 connected to the port 156 of valve 150D by a channel 178.

Valve 150D has its port 157 connected to channel 119E by a channel 179, its port 155 connected to channel 179 by a channel 180 having a choke 181 arranged therein, its port 154 connected to channel 178 by a channel 182 having a choke 183 arranged therein, and its port 153 connected to the cylinder 47 of control valve 104 by a channel 184 having a choke 185 arranged therein and a check valve 186 connected in parallel with choke 185.

It is to be noted that each valve 150 has its ports 156 and 157 connected to the motor outlets through free passages and its ports 154 and 155 connected to the motor outlets through choked passages which resist the flow of liquid therethrough and thereby permit liquid to flow freely from the outlet of the motor having the higher back pressure to port 156 or 157 and shift valve plunger 151 to a position in which port 153 is connected to the outlet of the motor having the lower back pressure.

For example, if plunger 151 of valve 150A were at the left and the back pressure on motor 102A should become greater than the back pressure on motor 102B, liquid would tend to flow from channel 119A through channels 160 and 162 and ports 154 and 153 of valve 150A but the flow therethrough is restricted by choke 163. Therefore, since the pressure in channel 160 is higher than the pressure in channel 161 and channel 160 is unrestricted, liquid will flow therethrough to port 156 and move plunger 151 of valve 150A toward the right to the position shown so that port 153 would be open to port 155 and the lower back pressure could extend from channel 119B through channels 161 and 164 and ports 155 and 153 into channel 166.

If plunger 151 of valve 150C were at the left and the back pressure on motor 102C should become greater than the back pressure on motor 102D, plunger 151 of valve 150C would be shifted to the right by the preponderance of pressure in channel 167 for the same reason that plunger 151 of valve 150A would be shifted to the right by the preponderance of pressure in channel 160. With plunger 151 of valve 150C in its right hand position as shown, the lower back pressure could extend from channel 119D through channels 168 and 171 and ports 155 and 153 into channel 173.

If plunger 151 of valve 150B were at the right and the back pressure on either of motors 102C and 102D should become greater than the back pressure of either of motors 102A and 102B, the pressure in channel 173 would become greater than the pressure in channel 166 and plunger 151 of valve 150B would be shifted to the left by the preponderance of pressure in channel 173 for the same reason that plunger 151 of valve 150A would be shifted to the right by the preponderance of pressure in channel 160. With plunger 151 of valve 150B in its left hand position as shown, the lower pressure in channel 166 could extend therefrom through channel 174 and valve 150B into channel 178.

If plunger 151 of valve 150D were at the right and the back pressure on motor 102E should become greater than the pressure in channel 178, plunger 151 of valve 150D would be shifted to the left by the preponderance of pressure in channel 179 for the same reason that plunger 151 of valve 150A would be shifted to the right by the preponderance of pressure in channel 160. With plunger 151 of valve 150D in its left hand position as shown, the lower pressure in channel 178 could extend therefrom through channel 182, valve 150D and channel 184 to cylinder 47 of control valve 104. An increase in the pressure in cylinder 47 above a predetermined minimum would cause piston 46 to shift valve plunger 35 of valve 104 toward the left to effect a reduction in pump displacement, and a decrease in the pressure in cylinder 47 below the predetermined minimum would permit spring 45 to shift plunger 35 toward the right to effect an increase in pump displacement as previously explained.

It will be obvious that the plunger 151 of each valve 150 is shifted by the higher of the two pressures prevailing at its ports 156 and 157 and that each valve 150 functions automatically to connect the lower of the two pressures to its port 153 so that control valve 104 is always operated and effects adjustment of the displacement of pump 101 in response to variations in the back pressure on the motor having the lowest back pressure regardless of which one of the motors has the lowest back pressure.

Since all of the motors are connected to the pump in parallel with each other, pump pressure prevails at the inlets of all of the motors and the pump must create a pressure high enough to enable the most heavily loaded motor to drive its load. The pressure drop across each motor varies in accordance with variations in the load on that motor and, since the same pressure prevails at the inlets of all of the motors, the most heavily loaded motor will have the greatest pressure drop thereacross and, consequently, the lowest back pressure.

By adjusting the displacement of the pump in response to variations in the back pressure on the motor having the lowest back pressure as previously explained, the pump will deliver liquid at just the rate required to enable all of the motors to operate at the individual speeds determined by the individual speed controls and the pump will create just enough pressure to effect operation of the motor requiring the highest pressure, thereby avoiding the waste of power and heating of the liquid which would result if the transmission were otherwise controlled.

The invention herein set forth may be modified in various other ways without departing from the scope thereof which is hereby claimed as follows:

1. A hydraulic transmission, comprising a pump having means for varying its displacement, a plurality of motors having the inlets thereof connected to the outlet of said pump and adapted to be simultaneously energized by liquid delivered thereto by said pump, means for controlling the speed of each of said motors including a choke for resisting the discharge of liquid from that motor and to thereby impose a back pressure on that motor and means for compensating for variations in the slip of that motor due to variations in the load on that motor, and means for effecting operation of said displacement varying means in response to variations in the back pressure on the motor having the lowest back pressure.

2. A hydraulic transmission, comprising a pump having means for varying its displacement, a plurality of motors having the inlets thereof connected to the outlet of said pump and adapted to be simultaneously energized by liquid delivered thereto by said pump, means for controlling the speed of each of said motors including a choke for resisting the discharge of liquid from that

motor and to thereby impose a back pressure on that motor and a constant pressure valve connected between that motor and said choke to maintain a substantially constant pressure at the inlet of said choke, and means for effecting operation of said displacement varying means in response to variations in the back pressure on the motor having the lowest back pressure.

3. A hydraulic transmission, comprising a pump having means for varying its displacement, means for supplying motive liquid to said displacement varying means including a control valve having hydraulic actuating means, a plurality of motors having the inlets thereof connected to the outlet of said pump and adapted to be simultaneously energized by liquid delivered thereto by said pump, means for controlling the speed of each of said motors by throttling the outflow from each motor and thereby imposing a back pressure on each motor, and means for connecting said valve actuating means to the outlet of the motor having the lowest back pressure.

4. A hydraulic transmission, comprising a pump having means for varying its displacement, means for supplying motive liquid to said displacement varying means including a control valve having hydraulic actuating means, a plurality of motors having the inlets thereof connected to the outlet of said pump and adapted to be simultaneously energized by liquid delivered thereto by said pump, means for controlling the speed of each of said motors by throttling the outflow from each motor and thereby imposing a back pressure on each motor, and means for connecting said valve actuating means to the outlet of the motor having the lowest back pressure and including one less selector valve than there are motors and each selector valve being connected to the outlets of two motors and operable by liquid from the outlet of the motor having the higher back pressure to a position to permit liquid to flow through said valve from the outlet of the other of those two motors.

5. A hydraulic transmission, comprising a pump having hydraulic means for varying its displacement and having means responsive to pump pressure reaching a given maximum for reducing its displacement until it is delivering just enough liquid to maintain that pressure substantially constant, means for supplying motive liquid to said displacement varying means including a control valve having hydraulic actuating means, a plurality of motors having the inlets thereof connected to the outlet of said pump and adapted to be simultaneously energized by liquid delivered thereto by said pump, means for controlling the speed of each of said motors by throttling the outflow from each motor and thereby imposing a back pressure on each motor, and means for connecting said valve actuating means to the outlet of the motor having the lowest back pressure.

6. A hydraulic transmission, comprising a pump having means for varying its displacement, a plurality of motors having the inlets thereof connected to the outlet of said pump and adapted to be simultaneously energized by liquid delivered thereto by said pump, means for controlling the speed of each of said motors by throttling the outflow from each motor and thereby imposing a back pressure on each motor, and means for effecting operation of said displacement varying means in response to variations in the back pressure on the motor having the lowest back pressure.

7. A hydraulic transmission, comprising a pump having means for varying its displacement, a plurality of motors having the inlets thereof connected to the outlet of said pump and adapted to be simultaneously energized by liquid delivered thereto by said pump, means for controlling the speed of each of said motors by throttling the outflow from each motor and thereby imposing a back pressure on each motor, means for effecting operation of said displacement varying means in response to variations in the back pressure on the motor having the lowest back pressure, each of said motor speed control means including, means for choking the outflow from the motor with which it is associated, means responsive to variations in the pressure of the liquid discharged by that motor relative to the pressure of the liquid delivered to that motor for adjusting said choking means to thereby compensate for variations in the slip of that motor due to variations in motor load, and means for adjusting said choking means in response to motor speed varying from a given speed.

8. A hydraulic transmission, comprising a pump having hydraulic means for varying its displacement, means for supplying motive liquid to said displacement varying means including a control valve having hydraulic actuating means, a plurality of motors having the inlets thereof connected to the outlet of said pump and adapted to be simultaneously energized by liquid delivered thereto by said pump, means for controlling the speed of each of said motors by throttling the outflow from each motor and thereby imposing a back pressure on each motor and by compensating for variations in the slip of that motor due to variations in the load on that motor, and means for connecting said valve actuating means to the outlet of the motor having the lowest back pressure.

9. A hydraulic transmission, comprising a pump having hydraulic means for varying its displacement, means for supplying motive liquid to said displacement varying means including a control valve having hydraulic actuating means, a plurality of motors having the inlets thereof connected to the outlet of said pump and adapted to be simultaneously energized by liquid delivered thereto by said pump, means for controlling the speed of each of said motors by throttling the outflow from each motor and thereby imposing a back pressure on each motor, and selector valve means connected between said valve actuating means and the outlets of said motors, said selector valve means being responsive to the differences in the pressures in said outlets for subjecting said valve actuating means to the pressure in the outlet of the motor having the lowest back pressure.

10. A hydraulic transmission, comprising a pump having means for varying its displacement, a plurality of motors having the inlets thereof connected to the outlet of said pump and adapted to be simultaneously energized by liquid delivered thereto by said pump, means for controlling the speed of each of said motors by throttling the outflow from each motor and thereby imposing a back pressure on each motor, and means for effecting operation of said displacement varying means in response to variations in the back pressure on the motor having the lowest back pressure, each of said motor speed control means including means for choking the outflow from the motor with which it is associated, and means responsive to vari-

ations in the pressure of the liquid discharged by that motor relative to the pressure of the liquid delivered to that motor for adjusting said choking means to thereby compensate for variations in the slip of that motor due to variations in motor load.

11. A hydraulic transmission comprising a pump having hydraulic means for varying its displacement, means for supplying motive liquid to said displacement varying means including a control valve having hydraulic actuating means, a plurality of motors having the inlets thereof connected to the outlet of said pump and adapted to be simultaneously energized by liquid delivered thereto by said pump, speed control means connected to the outlet of each motor to control the speed of each motor by throttling the outflow therefrom and thereby imposing a back pressure thereon, and means for connecting said valve actuating means to the outlet of the motor having the lowest back pressure, each of said speed control means including a choke for limiting the rate of discharge of liquid from the motor to which it is connected, a constant pressure valve connected between said choke and the outlet of that motor to maintain a substantially constant pressure at the inlet of said choke, and means for compensating for variations in the slip of that motor due to variations in the load thereon.

12. A hydraulic transmission comprising a pump having hydraulic means for varying its displacement, means for supplying motive liquid to said displacement varying means including a control valve having hydraulic actuating means, a plurality of motors having the inlets thereof connected to the outlet of said pump and adapted to be simultaneously energized by liquid delivered thereto by said pump, speed control means connected to the outlet of each motor to control the speed of each motor by throttling the outflow therefrom and thereby imposing a back pressure thereon, and means for connecting said valve actuating means to the outlet of the motor having the lowest back pressure, each of said speed control means including a main choke for limiting the rate of discharge of liquid from the motor to which it is connected, a constant pressure valve connected between said choke and the outlet of that motor to maintain a substantially constant pressure at the inlet of said choke, and a second choke connected in parallel with said main choke and adjustable in response to variations in the pressure at the outlet of that motor relative to the pressure at the inlet of that motor to vary the rate of flow therethrough to thereby compensate for variations in the slip of that motor due to variations in motor load.

13. A hydraulic transmission comprising a pump having hydraulic means for varying its displacement, means for supplying motive liquid to said displacement varying means including a control valve having hydraulic actuating means, a plurality of motors having the inlets thereof connected to the outlet of said pump and adapted to be simultaneously energized by liquid delivered thereto by said pump, speed control means connected to the outlet of each motor to control the speed of each motor by throttling the outflow therefrom and thereby imposing a back pressure thereon, a selector valve having two inlet ports connected to the outlets of two of said motors respectively and an outlet port adapted to communicate with one or the other of said inlet ports, and means for connecting said outlet port to said valve actuating means, said selector valve being responsive to a difference in the back pressure on said two motors for connecting the outlet of the motor having the lower back pressure to said outlet port.

14. A hydraulic transmission comprising a pump having hydraulic means for varying its displacement, means for supplying motive liquid to said displacement varying means including a control valve having hydraulic actuating means, a plurality of motors having the inlets thereof connected to the outlet of said pump and adapted to be simultaneously energized by liquid delivered thereto by said pump, speed control means connected to the outlet of each motor to control the speed of each motor by throttling the outflow therefrom and thereby imposing a back pressure thereon, and selector valve means one less in number than the number of motors connected between said valve actuating means and the outlets of all of said motors for causing said valve actuating means to be subjected to the pressure at the outlet of the motor having the lowest back pressure, each of said selector valve means having two inlet ports connected to the outlets of two motors and an outlet port connectable to said valve actuating means and adapted to communicate with one or the other of said inlet ports, each of said selector valve means being responsive to a difference in the back pressures on the two motors to which it is connected for connecting its outlet port to the outlet of the motor having the lower back pressure.

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