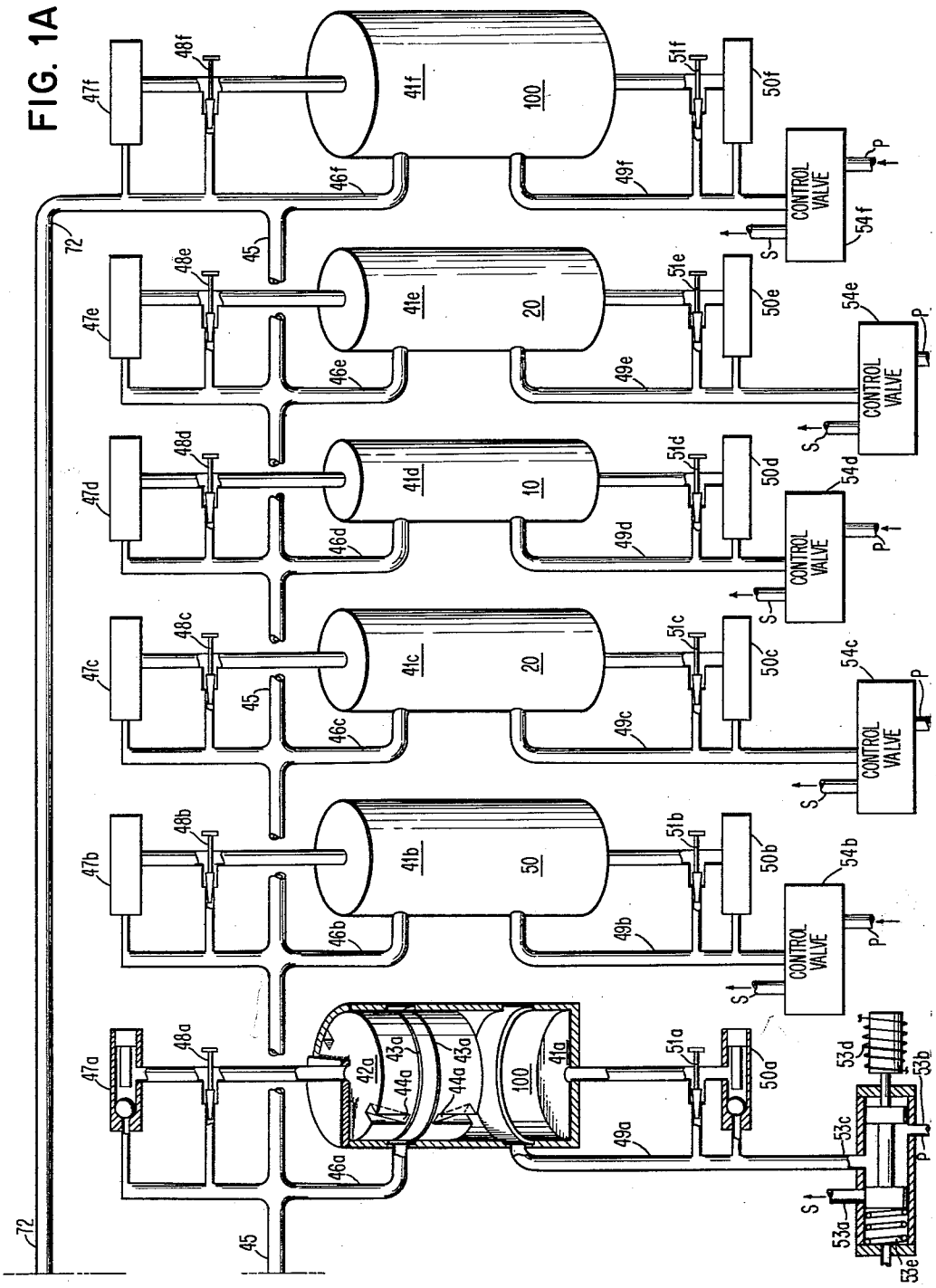
April 28, 1964 M. E. FREEMAN 3,130,549

HYDRAULIC POSITIONING SYSTEM

Filed Sept. 14, 1960 2 Sheets-Sheet 1

FIG. 1A



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HYDRAULIC POSITIONING SYSTEM

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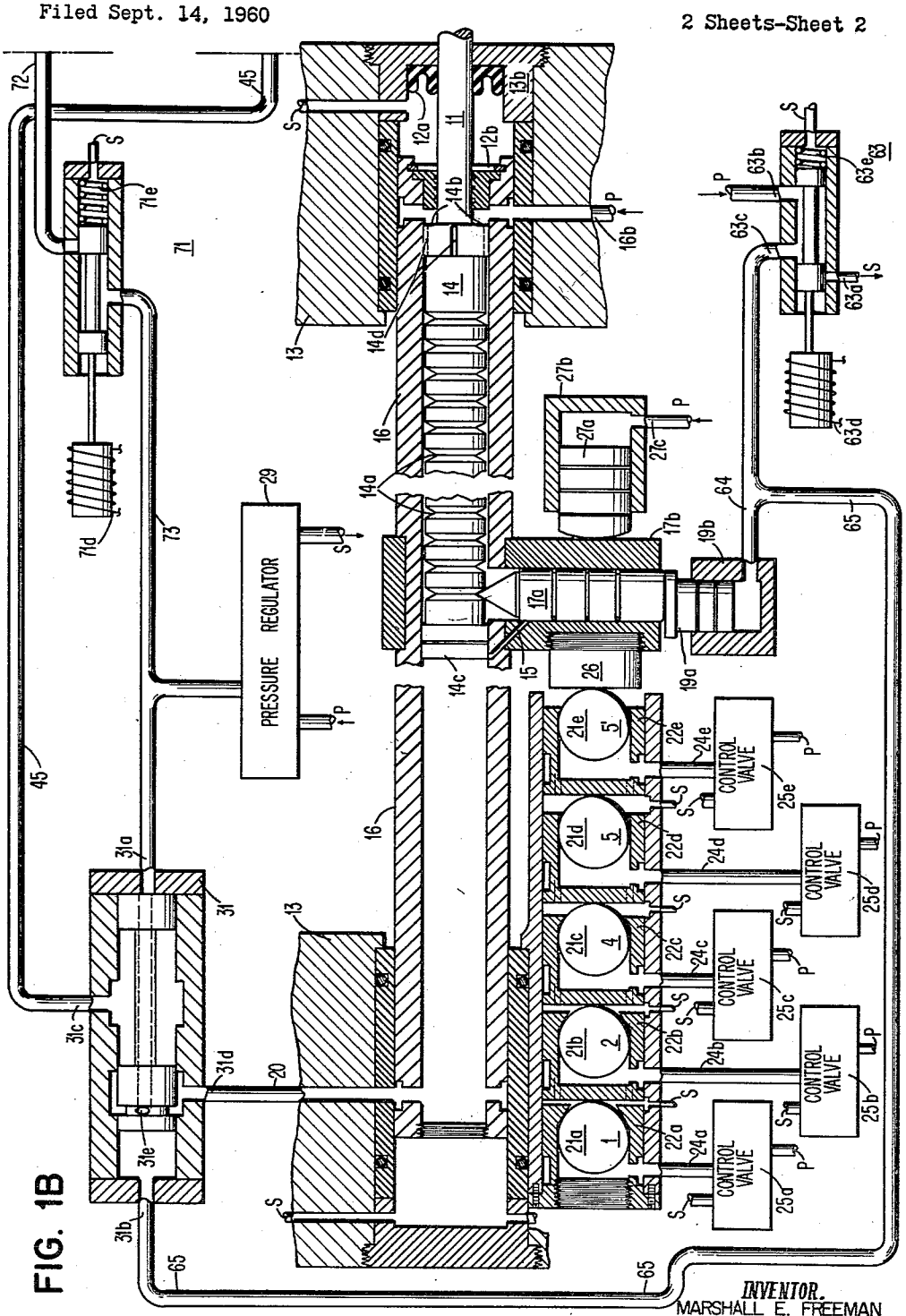


FIG. 1B

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HYDRAULIC POSITIONING SYSTEM

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6 Claims. (Cl. 60—54.5)

This invention relates in general to hydraulic positioning systems and relates more particularly to such positioning systems employing two types of positioning mechanisms.

Broadly, the present invention contemplates a hydraulic positioning system employing a volumetric adder device in the form of a glob adder positioning mechanism for large increments of movement, in conjunction with a cylinder adder device in the form of a ball or piston adder mechanism for smaller increments of movement, with both mechanisms cooperating with a shaft to be positioned. The glob adder utilized in the present invention comprises a plurality of cylinders of different volumes having pistons which are displaceable therein in response to actuation of control valves individually with the different cylinders. In the preferred embodiment, the glob adder cylinders are connected in parallel to the interior of a first cylinder in which a detented output shaft is disposed so that variations in the volumetric displacements of the glob adder pistons produce a displacement of the detented shaft relative to the first cylinder. The ball adder is mechanically connected to the first cylinder and produces movement of this first cylinder within a second cylinder in response to variations in the valving connections to the ball adder cylinders. Movement of the ball adder will also produce a corresponding movement of the detented output shaft, since the output shaft is either mechanically or hydraulically locked to the first cylinder.

The output shaft has provision for detenting the movement thereof within the inner cylinder for each unit of coarse positioning movement provided by the glob adder. In the preferred embodiment, in which the invention is utilized to position a transducer mechanism at any one of 250 discrete positions relative to a rotating recording disk, the glob adder elements provide positioning in increments which are even multiples of 10 units of movement. The ball adder elements provide increments of movement smaller than those provided by the glob adder, i.e. movements from 1 to 9 units. By thus combining the two types of positioning mechanisms in the novel manner taught in this invention, several significant advantages are obtained. The ball adder elements have positive displacements by nature so that no detent mechanism need be provided for increments of movement smaller than the smallest increment provided by the glob adder. By utilizing a glob adder only for relatively large increments of movement, detenting may be provided for this glob adder without requiring extremely fine spacing of the detent notches. This, in turn, permits the detent to correct for positioning errors approaching +5 increments of movement. If a detent notch were provided for each increment of movement, it will be seen that the largest error which could be corrected by the detent would be ±0.5 increment of movement. Even if multiple detents on a vernier spacing were utilized in an effort to alleviate the detent notch size problem discussed above, the tolerance problems in connection with the multiple detents themselves become considerable. By utilizing ball adders only for small increments of movement less than the smallest increment of movement provided by the glob adder, only a small number of ball adder elements are required, thus reducing the tolerance problems which would be associated with the use of a large number of

ball or piston adder elements to provide large overall movements.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of the preferred embodiment of the invention, as illustrated in the accompanying drawings, in which:

FIG. 1A diagrammatically illustrates the glob adder portion of one embodiment of the invention in connection with the positioning of a transducer mechanism relative to a rotating record disk; and

FIG. 1B is a continuation of FIG. 1A and illustrates the ball adder and the detented output shaft portions of the apparatus.

Referring to FIG. 1B by character of reference, numeral **11** designates an output shaft which is connected to a load to be positioned. Such a load may be of any suitable type which is to be accurately and rapidly positioned to any one of a number of discrete positions. As indicated above, the load in the described embodiment is assumed to be a transducer mechanism (not shown) which is to be positioned at any one of 250 discrete radial positions relative to a rotating disk. Shaft **11** extends through an opening in an end cap **13***b* in the right hand end of an outer cylinder **13** which represents a stationary element relative to the load to be positioned. Shaft **11** is provided with a detent spindle portion **14** which extends into an inner cylinder member **16** disposed within outer cylinder **13**. A low pressure seal **12***a* may be provided to seal the area of entry of shaft **11** through end plate **13***b*, and a high pressure seal **12***b* is provided to seal shaft **11** in inner cylinder **16**.

Spindle **14** is provided with a plurality of spaced grooves **14***a* which represent detent notches for detenting the movement of spindle **14** and shaft **11** relative to inner cylinder **16**. Detent grooves **14***a* of the detent spindle are engaged by a detent member **17***a* which is movable through an opening in the wall of cylinder **16** to engage one of the detent grooves. Detent **17***a* moves in a detent housing **17***b* and is urged into and out of engagement with a detent groove by means of controllable fluid pressure exerted against the face of a detent operating piston **19***a*. Detent operating piston **19***a* fits in a detent operating piston housing **19***b* which is fixed relative to shaft **14**, cylinder **16**, and detent **17***a*. Detent operating piston **19***a*, which is stationary, has an operating face broad enough to operate detent **17***a* over the range of motion imparted to detent **17***a* and detent housing **17***b* by the ball adder elements to be described below.

Spindle **14**, when undetented, is movable relative to inner cylinder **16** in response to variations in the flow of pressure fluid into or out of the left hand end of cylinder **16**. Variations in this flow of fluid through a conduit **20** into cylinder **16** produces changes in the position of the spindle **14** relative to cylinder **16** to thus produce changes in the position of output shaft **11**.

In the drawings, those connections labelled P are assumed to have a 500 p.s.i. pressure supplied thereto, and those connections labelled S are sump or exhaust connections. A bias pressure of 500 p.s.i. is supplied through a conduit **16***b* against piston face **14***b* on the right hand end of the detent spindle, tending to move this spindle to the left. Fluid under a pressure of approximately 275 p.s.i. is supplied to the left hand piston face **14***c* from a regulated pressure source **29** through a shuttle valve **31** and inlet conduit **20**. The surface area of piston face **14***c* is approximately twice the area of piston face **14***b*, so that when the detent is engaged with a detent groove, the forces acting on spindle **14** are approximately balanced. Piston face **14***b* is provided with a plurality of notches or grooves **14***d* around the periphery thereof to permit flow of the 500 p.s.i. bias fluid from conduit **16***b*

into cylinder 16 and against the face of detent 17a. This fluid exerts a force against the detent which forces the detent out of engagement with the notch when the pressure against detent operating piston 19a is removed by the operation of a detent valve to be described below.

Shuttle valve 31 is provided with a valve spool therein which is movable in response to variations in the pressures acting on the opposite faces of the spool. One face receives a 275 p.s.i. pressure from regulator 29 through a connection 31a, while the opposite face receives a 500 p.s.i. pressure through a connection 31b. When the 500 p.s.i. pressure is present at connection 31b, the valve spool moves to the right to cover a port 31d as shown in the drawing. Under these conditions, the 275 p.s.i. fluid from regulator 29 flows through connection 31a and the hollow interior of the valve spool to an opening 31e therein which leads to connection 31d, conduit 20 and the interior of cylinder 16. When the 500 p.s.i. pressure at connection 31b is released, the 275 p.s.i. pressure drives the valve spool to the left to establish communication through the valve body between a connection 31c and connection 31d.

Inner cylinder 16 is moved relative to outer cylinder 13 by means of a suitable mechanism such as a ball adder mechanism 21. Adder mechanism 21 may be of any suitable type, but preferably is a ball adder similar to that disclosed in my Patent 2,948,264, assigned to the same assignee as the present application. In such an adder mechanism, the elements include a plurality of balls 21a, 21b, 21c, 21d and 21e which are disposed in associated cylinders 22a, 22b, 22c, 22d and 22e to form five capsule units. In this ball adder, as described in detail in the above patent, the motion imparted to the load by each of the capsules is a function of the amount by which each ball projects from its associated capsule cylinder. From the drawing it will be seen that when each ball projects to the right from its associated cylinder, it will impart a motion to the right to the adjacent cylinder member, and the total displacement in the adder will be the sum of the displacements of the individual units. The right hand capsule unit 22e is mechanically connected to the inner cylinder 16 through the detent housing 17b by a member 26 so that movement of the ball adder mechanism is imparted to the inner cylinder 16 to move inner cylinder 16 and the output shaft 11 relative to outer cylinder 13. A bias force is applied to housing 17b and cylinder 16 by a ball adder bias piston 27a to oppose the movement imparted to cylinder 16 by the ball added mechanism and to move the element to the left when any of the ball adder cylinders are exhausted to sump. Bias piston 27a is disposed in a housing 27b in which a 500 p.s.i bias fluid is supplied through an inlet 27c.

To supply a displacing force to each of the balls 21a through 21e, a suitable fluid under pressure is supplied through inlet conduits 24a through 24e to the associated capsule cylinders. When pressure fluid is supplied to a given capsule cylinder, the associated ball therein is displaced to the right within the cylinder, while opening of a cylinder to atmosphere or sump through the associated inlet conduit releases the pressure against the associated ball so that the bias pressure exerted by bias piston 27a forces this ball to the left. The supply and exhaust of fluid to and from the cylinders through conduits 24a to 24e is under the control of valving which may be of any suitable type, such as three-way control valves 25a, 25b, 25c, 25d and 25e to be described below in connection with the glob adder control valving. The amounts of displacement of the individual capsule units may be varied in accordance with the characteristics of the load to be positioned, but in the particular embodiment disclosed herein, the displacements of the balls 21a, 21b, 21c, 21d and 21e are assumed to be 1 unit, 2 units, 4 units, 5 units and 5' units, respectively. The extra or 5' unit is utilized for the purpose to be described later on. The ball adder thus provides for increments of movement less than the 10-unit increments of movement of the glob adder.

The glob adder mechanism (FIG. 1A) is shown in the form of a plurality of cylinders of different volumes 41a, 41b, 41c, 41d, 41e and 41f. The cylinders represent displacements of 100, 50, 20, 10 20, and 100 units, respectively. Each of the cylinders is substantially identical except for its volume and hence only cylinder 41a is shown in detail in cross section. As shown by cylinder 41a, there is provided therein a piston 42a which is movable within the cylinder in response to variations in the pressures acting against the piston faces. As is well known in the volumetric adder art, pressure fluid may be supplied to the upper portion of cylinder 41a to exert a predetermined force against the upper surface of piston 42a. The presence of fluid under a similar pressure in the lower portion of the cylinder will exert a similar force to retain the piston in the upper position so long as the lower portion of the cylinder is not open to exhaust or sump. Each of the pistons is also preferably provided with a plurality of damping grooves 44a to provide damping of the movement of the piston within the cylinder.

Pressure fluid is supplied to cylinder 41a through an inlet conduit 45 and a branch conduit 46a. Similar branch conduits 46b, 46c, 46d, 46e and 46f supply cylinders 41b, 41c, 41d, 41e and 41f. Each of cylinders 41a through 41f is also preferably provided with a return bypass valve, such as the 47a shown for cylinder 41a. Return bypass valve 47a is connected to conduits 45 and 46a and communicates with the top of cylinder 41a. The purpose of this bypass valve is to provide an initial surge of pressure fluid against the top of the associated piston at the start of movement for this piston, as will be described more in detail below. Each cylinder is also preferably provided with an adjustable needle valve, such as the valve 48a shown for cylinder 41a. Cylinders 41b through 41f are similarly provided with return bypass valves 47b through 47f and adjustable needle valves 48b through 48f. A conduit 72 is connected to conduit 46f for a purpose to be described below.

The bottom or exhaust ends of each of the cylinders is connected to an associated control valve through a conduit such as conduit 49a shown for cylinder 41a. The exhaust connections for cylinder 41a are provided with a return bypass 50a and a needle throttling valve 51a. The exhaust connections of cylinders 41b through 41f are similarly provided with return bypass valves 50b through 50f and needle valves 51b through 51f. The control of the connection of the lower ends of the cylinders to sump or pressure may be exercised selectively by means such as the three-way control valve 53 shown for cylinder 41a. As shown schematically in the drawing by a spool valve, valve 53 has a sump connection 53a, a pressure connection 53b to which pressure fluid is supplied, and a cylinder connection 53c leading to conduit 49a and the lower end of cylinder 41a. When solenoid 53d is de-energized, the elements are in the position shown in the drawing, in which pressure fluid from pressure conduit 53b is supplied through cylinder conduit 53c and conduit 49a to cylinder 41a, while the sump connection 53a is closed off from conduits 53b, 53c by the valve spool element. When solenoid 53d is energized, this moves the valve spool assembly to the left against the action of spring 53e to block off pressure conduit 53b and establish communication between cylinder conduit 53c and sump conduit 53a. This latter action permits pressure fluid from the lower portion of cylinder 41a to flow through conduit 49a and valve 53 to sump, thus releasing the pressure against the lower surface of piston 42a and permitting the pressure against the upper piston face to push the piston downwardly. Each of the other glob adder cylinders is provided with a similar three-way control 54b, 54c, 54d, 54e and 54f to selectively control the pressure fluid connections to the cylinder. It will be understood that the control

valves 25*a* through 25*e* for the ball adder elements may be similar to valve 53.

In summary of the operation so far, the load to be positioned is connected to shaft 11 which is integral with the detented spindle 14. The movement of spindle 14 within the inner cylinder 16 is under control of the glob adders 41*a* through 41*f* to produce increments of movement of this spindle within the cylinder 16. Cylinder 16, in turn, is movable relative to outer cylinder 13 by means of the ball adder elements 21*a* through 21*e* which are mechanically connected to cylinder 16 and which move this cylinder, together with detent spindle 14 and shaft 11, relative to the outer cylinder 13.

The operation of the present invention may best be understood by considering the operation of the elements for a representative positioning of a load. As indicated above, it is assumed that the load to be positioned in the illustrated embodiment is in the form of one or more transducers which are to be selectively positioned at any one of 250 radial track positions on a magnetic recording disk. After positioning, the transducer would record on or reproduce from the selected track and then another positioning operation would take place to locate the transducer at the next selected track. Under these circumstances, the smallest increment of movement provided by the glob adder would correspond to a movement of 10 tracks, and each of the detent notches 14*a* on detent spindle 14 thus corresponds to a movement of 10 tracks. Similarly, the ball adder mechanism would provide increments of movement of less than 10 tracks. Assume that all the pistons 41*a* through 41*f* are in the uppermost position shown in the drawing, and that the system is full of pressure fluid, with all the control valves de-energized so that none of the glob adder or ball adder cylinders are open to sump. Under these conditions, pressure fluid will be supplied to each of the capsule units 21*a* through 21*e* of the ball adder through their associated control valves to move each of these units to the right, as shown in FIG. 1B. With both the glob adder cylinders and the ball adder cylinders filled with pressure fluid, detent spindle 14 and output shaft 11 will be positioned at the extreme right as shown in the drawing and detent 17*a* will be engaged with the detent notch 14*a* on the extreme left hand end of spindle 14.

Assume that it is desired to move the shaft 11 and its associated transducer head assembly to position #155 out of the possible 250 different positions. It is understood that in the assumed application of the invention to a data recording system, another part of the system is operative to determine the track "address" or location at which magnetic recording or reproduction is to take place and that such means are operative in response to the determination of the desired track address to generate the appropriate signals for energizing the proper ones of the glob adder and ball adder control valves. Under these circumstances, input signals are supplied to the control valves for cylinders 41*a* and 41*b* of the glob adders, as well as to the control valve for unit 22*d* of the ball adder. That is, as indicated by the control valve 53 for cylinder 41*a*, solenoid winding 53*d* thereof is energized to connect cylinder connection 53*c* to sump connection 53*a* and close off pressure connection 53*b*. Similarly, cylinder 41*b* of the glob adder and capsule unit 22*d* of the ball adder are connected to sump through their associated control valves. Opening of cylinders 41*a* and 41*b* to exhaust through their associated control valves permits pistons 42*a*, 42*b* to begin to move downwardly in the cylinders. Similarly, opening of cylinder 22*d* to exhaust permits the bias pressure against bias piston 27*a* to force the ball adder assembly and cylinder 16 to the left by an amount corresponding to the distance by which ball 21*d* protruded from cylinder 22*d*, the effect of which is described below.

Simultaneously with the above energization of the control valves for cylinders 41*a*, 41*b* and ball adder capsule 22*d*, a detent valve 63 (FIG. 1B) is de-energized by a positioning signal which is substantially simultaneous with the signals which energize the different control valves. Detent valve 63 includes a solenoid 63*d* which moves a valve spool assembly to establish communication between an outlet connection 63*c* and either a pressure connection 63*b* or a sump connection 63*a*. When solenoid 63*d* is energized, it overcomes a spring 63*e* to move the spool assembly to cover sump connection 63*a* and supply pressure fluid from pressure connection 63*b* to outlet connection 63*c*. When solenoid 63*d* is de-energized, spring 63*e* moves the valve spool assembly to cover pressure port 63*b* and connect outlet connection 63*c* to sump connection 63*a*.

Outlet connection 63*c* communicates both with the detent operating piston chamber 19*b* and detent piston 19*a* therein through a conduit 64 and with the bias connection 31*b* of shuttle valve 31 through a conduit 65. De-energization of solenoid 63*d* thus exhausts the detent operating piston chamber to sump to permit the fluid acting on the face of detent 17*a* to drive the detent out of engagement with a notch 14*a*, as discussed above. De-energization of solenoid 63*d* also exhausts the shuttle valve connection 31*b* to sump to permit the 275 p.s.i. at inlet connection 31*a* to drive the valve spool to the left. In this connection, it is important that no oil be forced into or out of the circuit in cylinder 16 by virtue of the detent 17*a* being withdrawn before the regulated pressure source is disconnected. To insure against this, the area of the face of the detent operating piston 19*b* is chosen such that, during the undetenting cycle, the pressure generated by the shuttle valve spool in moving to the left is sufficient to momentarily maintain in conduits 64 and 65 a pressure greater than the detent return pressure. This transient effect maintains detent 17*a* in engagement with the detent groove on spindle 14 until the shuttle valve spool has completed its travel to the left to disconnect the 275 p.s.i. pressure fluid of regulator 29 from cylinder 16. When the shuttle valve has completed its stroke to the left hand position, the transient pressure in conduits 64 and 65 subsides and detent 17*a* is then free to move out of engagement with spindle 14.

With piston 42*a* free to move within cylinder 41*a*, the bias pressure against the right hand face 14*b* of the detent spindle overcomes the pressure against the opposite piston face 14*c* and causes shaft 11 and detent spindle 14 to move to the left within cylinder 16, displacing oil from the left hand end of cylinder 16 into conduit 20. This displaced oil flows through conduit 20, shuttle valve 31 and conduit 45 to the conduit 46*a* of cylinder 41*a*. This flow of fluid through conduit 45 and conduit 46*a* will temporarily unseat the ball check in the return bypass 47*a* to permit some of this fluid to flow through the check valve into the top of cylinder 41*a*, thus exerting an accelerating force against the piston 42*a* within this cylinder. This action accelerates the movement of this piston within the cylinder to insure rapid operation of the positioning device. Simultaneously with the above described action in connection with cylinder 41*a*, cylinder 41*b* is similarly vented to sump and an amount of pressure fluid corresponding to the volume of cylinder 41*b* is displaced from the left hand end of cylinder 16. This displaced fluid will, of course, also flow through conduit 20, shuttle valve 31 and conduit 45 to conduit 46*b* into the upper portion of cylinder 41*b* to displace the piston 42*b* therein downwardly.

Thus, piston 14 will displace from cylinder 16 an amount of oil corresponding to the combined volumes of cylinders 41*a*, 41*b*. This combined volume in the present example is assumed to correspond to 150 units of movement of the shaft 11, thus representing 15 detented increments on detent spindle 14. Detent spindle 14 will thus have moved to the left an amount represented by 15 detent notches 14*a*, so that the 15th detent notch from

the left hand end will then be positioned within cylinder 16 adjacent detent 17a.

Simultaneously with the above described action for the glob added cylinders, ball adder cylinder 23d was exhausted to sump through its associated control valve. The release of pressure fluid in cylinder 22d will allow the bias pressure against piston face 27a to move ball 21d to the left within cylinder 22d an amount corresponding to 5 units of movement. This movement of ball 21d, will, of course, result in a corresponding movement of cylinder 21e and member 26 to displace these elements to the left an amount corresponding to 5 units of movement. Since member 26 is rigidly connected to cylinder 16, cylinder 16 will also move 5 units to the left, with detented spindle 14 locked thereto by virtue of the pressure fluid force exerted against the face of the piston 14c.

In summary of the operation thus far, the exhausting of cylinders 41a and 41b to sump has permitted spindle 14 and shaft 11 to move 150 units of movement within cylinder 16, while the exhausting of cylinder 22d to sump has permitted the ball adder assembly and the attached cylinder 16 to move to the left 5 units carrying with it the detent spindle 14 and shaft 11. Thus, the total movement to the left of shaft 11 is the sum of the 150 units of movement as a result of the glob adder control and 5 units of movement from the ball adder control, resulting in a total of 155 units of movement to the left.

When the load which is connected to shaft 11 is located at the desired track position relative to the disk surfaces, a signal is generated by means (not shown) indicating that the transducer is over the desired recording track. This signal is supplied to energize solenoid 63d of the detent valve 63. Energization of solenoid 63d overcomes spring 63e to drive the valve spool to cover sump connection 63a and supply pressure fluid from pressure connection 63b to outlet connection 63c and conduits 64 and 65. Supplying of pressure fluid to conduit 64 supplies pressure fluid to the bottom of the detent operating piston 19a to drive this piston upwardly and drive the detent 17a into engagement with the detent notch immediately adjacent thereto. Thus, detent 17a is locked in a detent groove 14a to firmly lock spindle 14 to cylinder 16. Supplying of pressure fluid to conduit 65 provides a force against the left hand face of the shuttle valve spool to drive this valve stem to the right against the 275 pound pressure from regulator 29. This movement of the shuttle valve stem breaks the fluid communication between conduit 45 and conduit 20 leading to the interior of cylinder 16. Under these conditions the 275 p.s.i. fluid is supplied from regulator 29 through connection 31a and the hollow valve spool of the shuttle valve 31 and out of the opening 31e therein to conduit 20 and the interior of cylinder 16, thus approximately balancing the forces on piston 14 and calibrating the quantity of fluid in cylinder 16 by allowing communication of cylinder 16 to the pressure regulator for the addition or subtraction of oil.

Assuming that following the positioning operation to locate the transducers at the track 155 position as described above, it is desired to move the transducer to the track 135 position, the operation would be as follows. Detent cylinder 19b is first exhausted by detent valve 63 to release detent piston 19a and drop out detent 17a, thus freeing spindle 14 for movement in cylinder 16. For the track 155 positioning operation described above, volumetric adder cylinders 41a and 41b were connected to sump by their respective control valves to permit 150 units of fluid to be displaced from the interior of cylinder 16 into the tops of volumetric adder cylinders 41a, 41b. The extra five units of displacement to produce the total of 155 units of displacement was provided by unit 21d of the ball adder device. To move from the track 155 position back to track 135, the address signal to the control valves would indicate that cylinder 41a (corresponding to 100 tracks of displacement) would remain connected to sump, while cylinder 41b (corresponding to the 50 units of movement) should be returned to the pressure connection. The address signal would further indicate that cylinder 41c (corresponding to 20 units of movement) and adder cylinder 41d (corresponding to 10 units of movement) should be connected to sump. The address signal would additionally indicate that unit 21d of the ball adder device should remain in the exhaust or sump condition which it was in to provide the five units of displacement for the track 155 positioning operation.

Under these conditions, the address signal causes control valve 54b associated with cylinder 41b to be moved from its sump connection which it had for the track 155 position, to the pressure position. Similarly, control valves 54c and 54d for cylinders 41c and 41d, respectively, are moved from the pressure condition, which they had for the track 155 position, to the sump position. With cylinder 41b in the pressure position, pressure fluid is supplied through control valve 54b and conduit 49b to drive the piston in cylinder 41b upwardly, thus displacing 50 units of hydraulic fluid out of the top of cylinder 41b. Simultaneously with this movement of the piston in cylinder 41b, control valves 54c and 54d exhaust their associated cylinders 41c, 41d to sump to draw into the tops of these two cylinders 20 and 10 units, respectively, of hydraulic fluid. Since hydraulic fluid is being forced out of cylinder 41b, while hydraulic fluid is being drawn into cylinders 41c, 41d, the net result of the changes in the connections of all three of these cylinders, as seen in conduit 45, will be the difference between the volume of cylinder 41b on the one hand and the combined volume of cylinders 41c, 41d on the other hand. Since this difference represents an amount of hydraulic fluid corresponding to 20 units of movement, and this net of 20 units of fluid is a fluid flow out of cylinder 41b, the net result of the above described changes in connections for cylinders 41b, 41c, 41d will be a flow of 20 units of fluid through conduit 45, shuttle valve 31, and conduit 20 into the left hand end of cylinder 16.

This flow of a net of 20 units of fluid into the interior of cylinder 16 will exert a pressure against piston face 14c to drive spindle 14 and load shaft 11 to the right 20 units of movement against the action of the bias pressure on the right hand face 14b of the detent spindle. Since the change from the track 155 position to the track 135 position requires no change in the connections of the ball adder device (the five unit ball adder element 21d being exhausted to sump for both conditions), there is no change in the ball adder element for this positioning.

When spindle 14 and load shaft 11 reach their new position in cylinder 16, this new position corresponding to the track 135 position or 20 tracks less than the track 155 position, the 13th detent notch from the left hand end of detent spindle 14 will be positioned within cylinder 16 adjacent detent 17a. When the "on track" signal is received, as described above, detent 17a is driven into this 13th detent notch to securely lock spindle 14 to cylinder 16.

Thus the track 135 position is obtained by the combination of 100 units of movement produced from volumetric adder cylinder 41a, 20 units of movement from volumetric adder cylinder 41c, ten units of movement from volumetric adder cylinder 41d, and five units of movement from ball adder element 21d. Similarly, any other track position between the track 0 position and the track 250 position may be reached by appropriate combinations of the connections of the volumetric adder cylinders and ball adder cylinders.

A rezero valve is provided in the present apparatus for recalibrating the hydraulic system at the start of a new period of operation, such as after a period of inactivity,

or whenever there is any reason to suspect that there is air in the hydraulic lines. The "rezeroing" operation operates in the following manner. Rezero valve **71** (FIG. 1B) is provided with a solenoid **71***d* which is energized to move a valve spool to establish communication between conduit **72** and a conduit **73** against the action of a spring **71***e*. When the rezeroing operation is performed, detent **17***a* is withdrawn and shuttle valve **31** is in the left hand position opposite to that shown in the drawing. Under these conditions, and with rezero valve **71***d* energized, pressure fluid from regulator **29** is supplied through conduit **73** and valve **71** to conduit **72**, thence back to conduit **45** and through shuttle valve **31** and conduit **20** to the interior of cylinder **16**. This supply of pressure fluid from regulator **29** drives spindle **14** and shaft **11** to the right past the last detent stop on spindle **14**. When the spindle has travelled past the last detent stop thereon, a bleed hole **15** is opened to supply 500 p.s.i. bias pressure fluid through this bleed hole opening into cylinder **16** and reverse the flow of oil in this cylinder. With bleed hole opening **15** uncovered, the 500 pound pressure fluid flows through conduit **20**, shuttle valve **31**, conduit **45**, conduit **72**, rezero valve **71** and conduit **73** back to regulator **29**, thus driving the fluid out of regulator **29** and bringing new fluid into the closed system to remove any air which may have caused errors in the positioning. Thus regulator **29** acts both to supply fluid to the system and to absorb fluid from the system to maintain the pressure of approximately 275 p.s.i. When the rezeroing operation is completed, rezero valve **71** is de-energized to close off conduit **73** from conduit **72**. Detent **17***e* is then actuated to engage the first detent notch on the spindle in the same manner as a normal detent operation, and the system is then ready to commence positioning operations as described above.

In the embodiment described herein, it will be recalled that the ball adder mechanism has two elements representing displacements of five units each. This second or 5′ element is for use in conjunction with the twenty unit displacement **41***c* of the glob adder to produce a total displacement of 25 units. The use of a ball adder element and a glob adder element to produce a displacement of 25 units simplifies the electronic logic required to set up the control valves for addressing. It will be noted that if a displacement of 25 units were to be provided by a single glob adder element, this would complicate the detenting scheme by requiring additional intermittent detent notches on spindle **14**, since the detent notches as shown are spaced in even multiples of 10 units of movement. The ability of the actuating mechanism to decode address signals as described above illustrates the adaptability of this type of positioning mechanism to a wide variety of addressing schemes.

What is claimed is:

1. A hydraulic positioning system for positioning a load device at any one of a plurality of discrete positions comprising a first cylinder which is stationary relative to said load device, a second cylinder disposed in and movable relative to said first cylinder, an output shaft forming a piston in said second cylinder and extending therefrom for connection to said load device, a volumetric adder having a plurality of cylinder elements hydraulically communicating with the interior of said second cylinder for varying the position of said shaft relative to said second cylinder, said volumetric adder elements providing increments of movement of said shaft and load device which are multiples of the smallest increment represented by adjacent ones of said positions, cylinder adder means mechanically connected to said second cylinder for moving said second cylinder and said output shaft relative to said first cylinder, said cylinder adder providing increments of movement of said shaft in the range between the smallest increment of movement required and the smallest increment of movement provided by said volumetric adder, and control means for controlling said volumetric adder and said cylinder adder.

2. A hydraulic positioning system for positioning a load device at any one of a plurality of discrete positions comprising a first cylinder which is stationary relative to said load device, a second cylinder disposed in and movable relative to said first cylinder, an output shaft forming a piston in said second cylinder and extending therefrom for connection to said load device, a volumetric adder having a plurality of cylinder elements hydraulically communicating with the interior of said second cylinder for varying the position of said shaft relative to said second cylinder, said volumetric adder elements providing increments of movement of said shaft and load device which are multiples of the smallest increment represented by adjacent ones of said positions, detent means for detenting said output shaft relative to said second cylinder for increments of movement provided by said volumetric adder, cylinder adder means mechanically connected to said second cylinder for moving said second cylinder and said output shaft relative to said first cylinder, said cylinder adder providing increments of movement of said shaft in the range between the smallest increment of movement required and the smallest increment of movement provided by said volumetric adder, and control means for controlling said volumetric adder and said cylinder adder.

3. A hydraulic positioning system for positioning a load device at any one of a plurality of discrete positions comprising a first cylinder which is stationary relative to said load device, a second cylinder disposed in and movable relative to said first cylinder, an output shaft forming a piston in said second cylinder and extending therefrom for connection to said load device, a volumetric adder having a plurality of cylinder elements of different volumes hydraulically communicating with the interior of said second cylinder for varying the position of said shaft relative to said second cylinder, said volumetric adder elements providing increments of movement of said shaft and load device which are multiples of the smallest increment represented by adjacent ones of said positions, cylinder adder means mechanically connected to said second cylinder for moving said second cylinder and said output shaft relative to said first cylinder, said cylinder adder providing increments of movement of said shaft in the range between the smallest increment of movement required and the smallest increment of movement provided by said volumetric adder, and control means for controlling said volumetric adder and said cylinder adder.

4. A hydraulic positioning system for positioning a load device at any one of a plurality of discrete positions comprising a first cylinder which is stationary relative to said load device, a second cylinder disposed in and movable relative to said first cylinder, an output shaft forming a piston in said second cylinder and extending therefrom for connection to said load device, a volumetric adder having a plurality of cylinder elements of different volumes hydraulically communicating with the interior of said second cylinder for varying the position of said shaft relative to said second cylinder, said volumetric adder elements providing increments of movement of said shaft and load device which are multiples of the smallest increment represented by adjacent ones of said positions, detent means for detenting said output shaft relative to said second cylinder for increments of movement provided by said volumetric adder, cylinder adder means mechanically connected to said second cylinder for moving said second cylinder and said output shaft relative to said first cylinder, said cylinder adder providing increments of movement of said shaft in the range between the smallest increment of movement required and the smallest increment of movement provided by said volumetric adder, and control means for controlling said volumetric adder and said cylinder adder.

5. A hydraulic positioning system for positioning a load device at any one of a plurality of discrete positions com-

prising a first cylinder which is stationary relative to said load device, a second cylinder disposed in and movable relative to said first cylinder, an output shaft forming a piston in said second cylinder and extending therefrom for connection to said load device, a volumetric adder having a plurality of cylinder elements of different volumes, first control valve means associated with said volumetric adder for controlling the connection of different ones of said cylinder elements to the interior of said second cylinder to vary the position of said shaft relative to said second cylinder, said volumetric adder elements providing increments of movement of said shaft and load device which are multiples of the smallest increment represented by adjacent ones of said positions, cylinder adder means mechanically connected to said second cylinder, and second control valve means associated with said cylinder adder for energizing the different elements of said cylinder adder to move said second cylinder and said output shaft relative to said first cylinder, said cylinder adder providing increments of movement of said shaft in the range between the smallest increment of movement required and the smallest increment of movement provided by said volumetric adder.

6. A hydraulic positioning system for positioning a load device at any one of a plurality of discrete positions comprising a first cylinder which is stationary relative to said load device, a second cylinder disposed in and movable relative to said first cylinder, an output shaft forming a piston in said second cylinder and extending therefrom for connection to said load device, a volumetric adder having a plurality of cylinder elements of different volumes, first control valve means associated with said volumetric adder for controlling the connection of different ones of said cylinder elements to the interior of said second cylinder to vary the position of said shaft relative to said second cylinder, said volumetric adder elements providing increments of movement of said shaft and load device which are multiples of the smallest increment represented by adjacent ones of said positions, detent means for detenting said output shaft relative to said second cylinder for increments of movement provided by said volumetric adder, cylinder adder means mechanically connected to said second cylinder, and second control valve means associated with said cylinder adder for energizing the different elements of said cylinder adder to move said second cylinder and said output shaft relative to said first cylinder, said cylinder adder providing increments of movement of said shaft in the range between the smallest increment of movement required and the smallest increment of movement provided by said volumetric adder.

No references cited.