

- [54] MOTION COMPENSATION AND/OR WEIGHT CONTROL SYSTEM
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- [51] Int. Cl.² B66D 1/50
- [58] Field of Search 254/172, 173 R; 175/27, 175/5, 7; 173/4, 6; 60/325, 413, 416; 91/390; 92/108, 110, 134; 267/124, 125

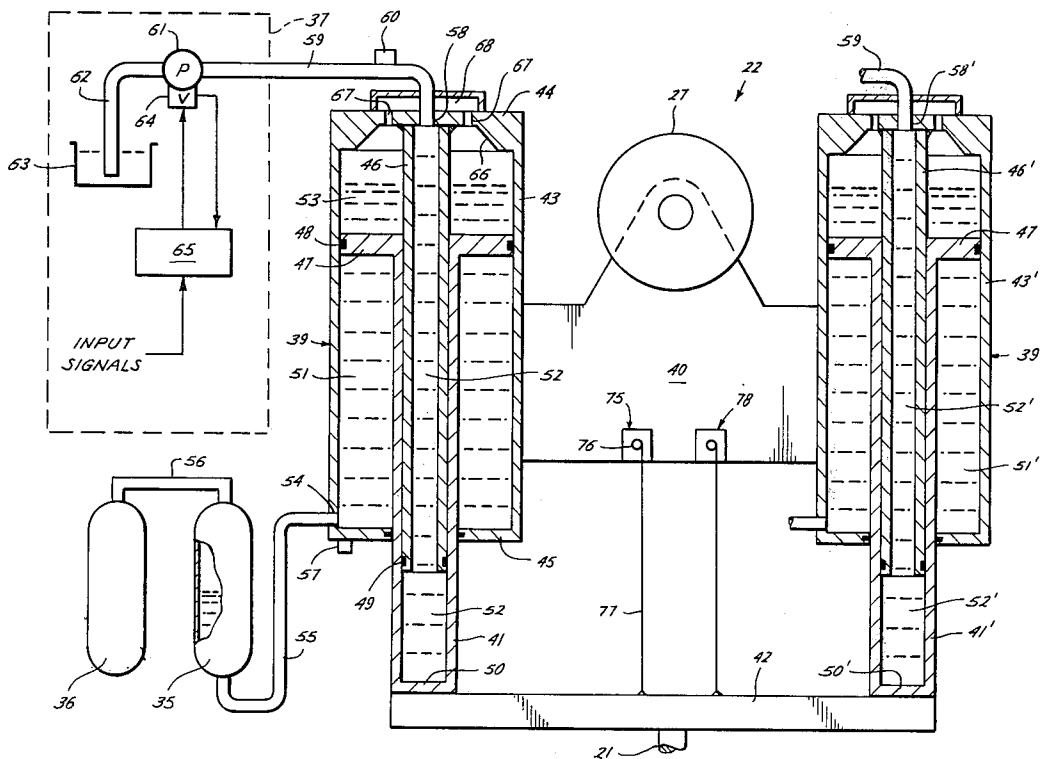
[57] **ABSTRACT**

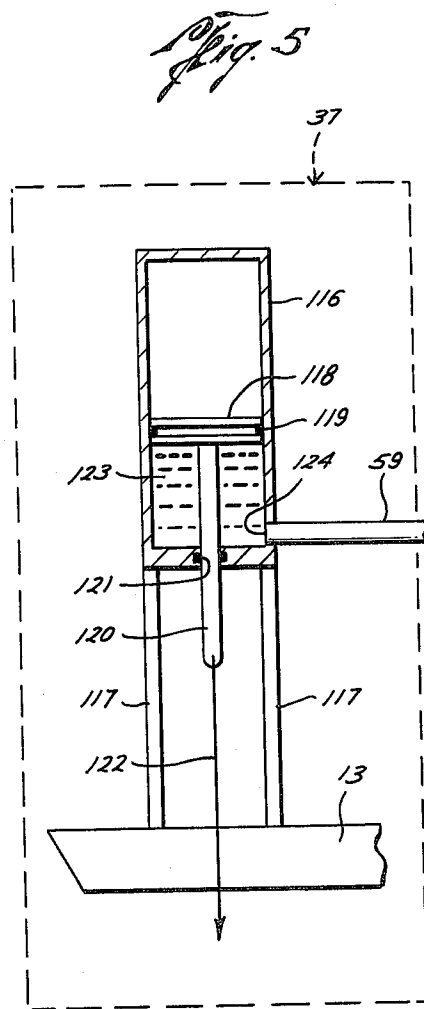
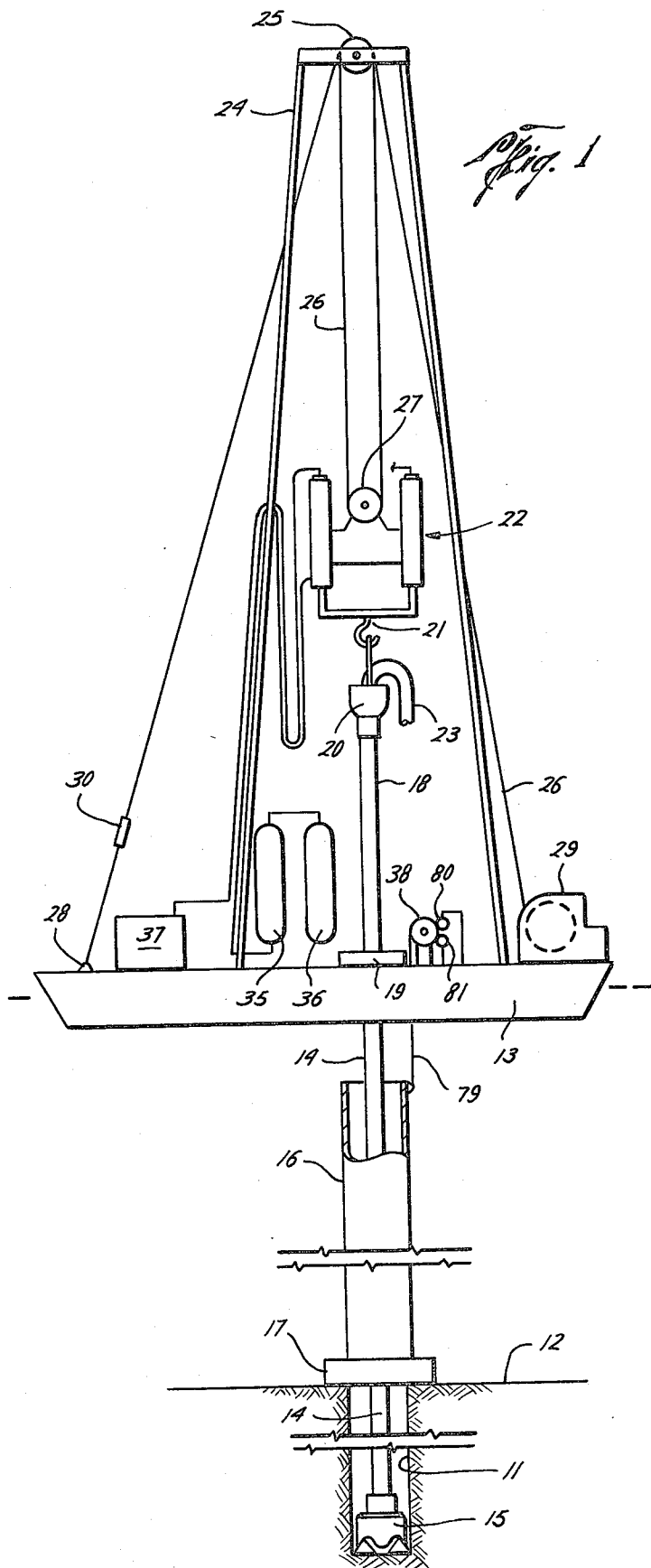
A motion compensation and/or weight control system mounted from a load-supporting assembly for supporting a load which is movable relative to the load-supporting assembly. The motion compensation and/or weight control system comprises an improved expansible and contractible mechanism mounted between the load-supporting assembly and its load. The improved expansible and contractible mechanism includes a passively operated piston and cylinder assembly for supporting the load and an actively operated piston and cylinder assembly for providing biasing forces. The system may be operated either in the pressure mode or in the position mode. When the system is operated in the position mode, hydraulic fluid is actively supplied to and withdrawn from the piston and cylinder assembly responsive to the velocity of the expansion and contraction of the expansible and contractible mechanism and the velocity of the vertical movement of the floating structure relative to the earth.

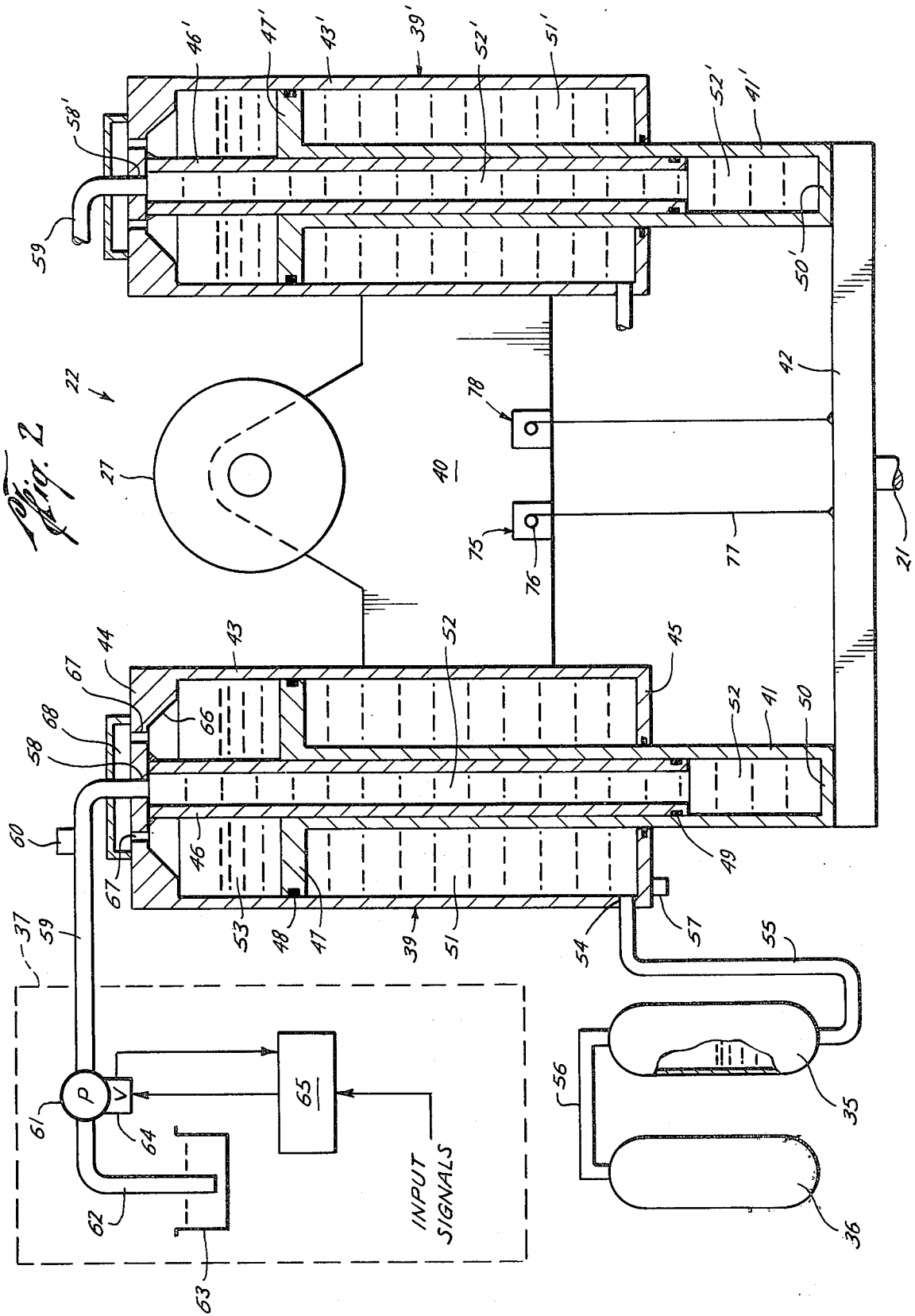
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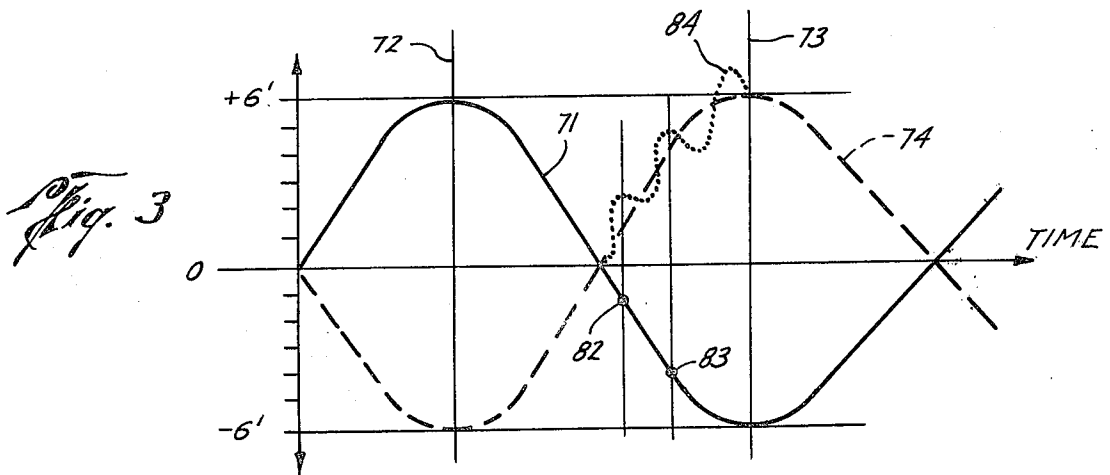
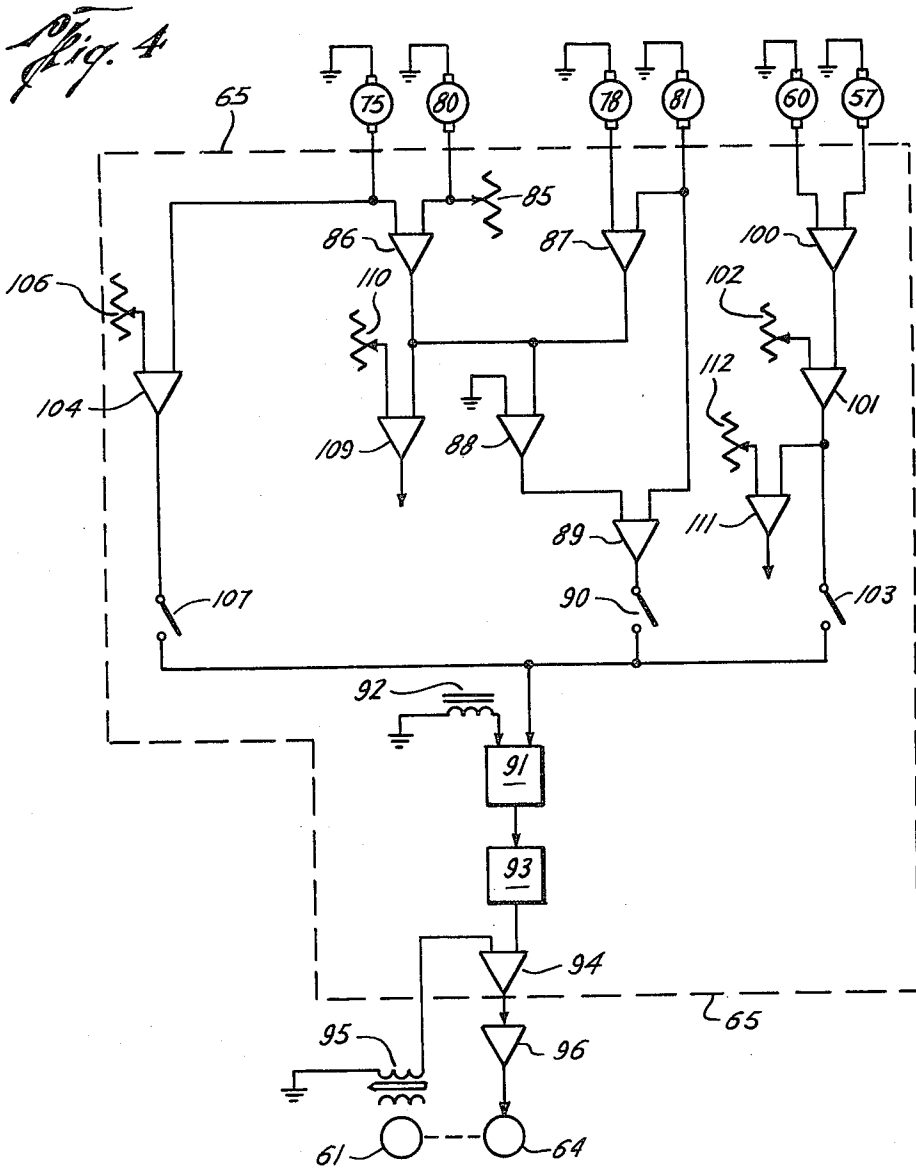
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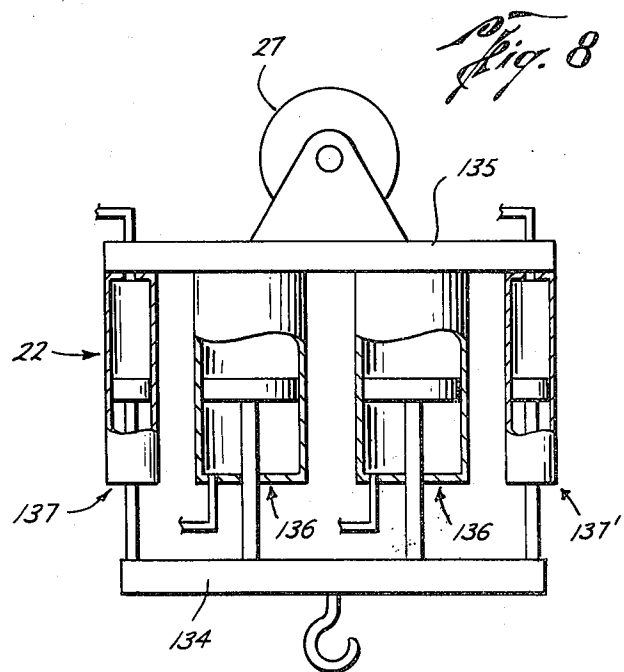
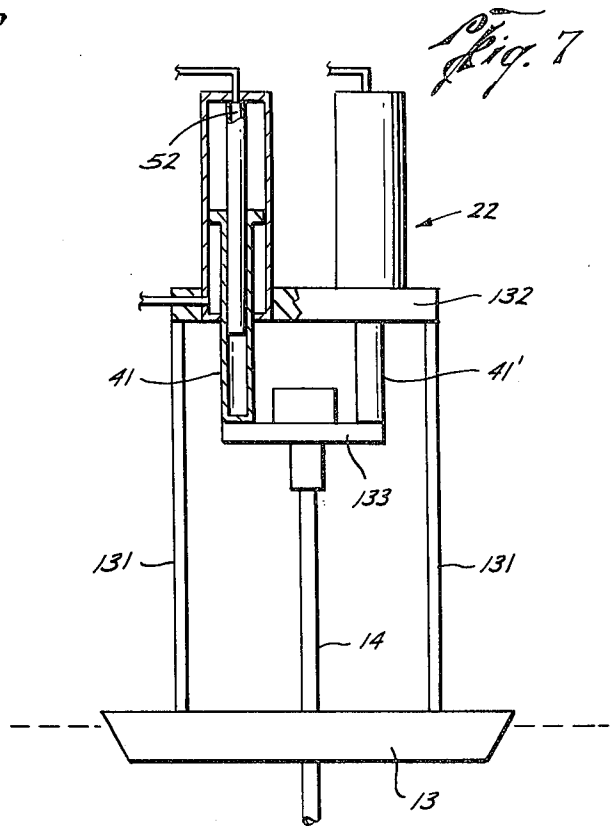
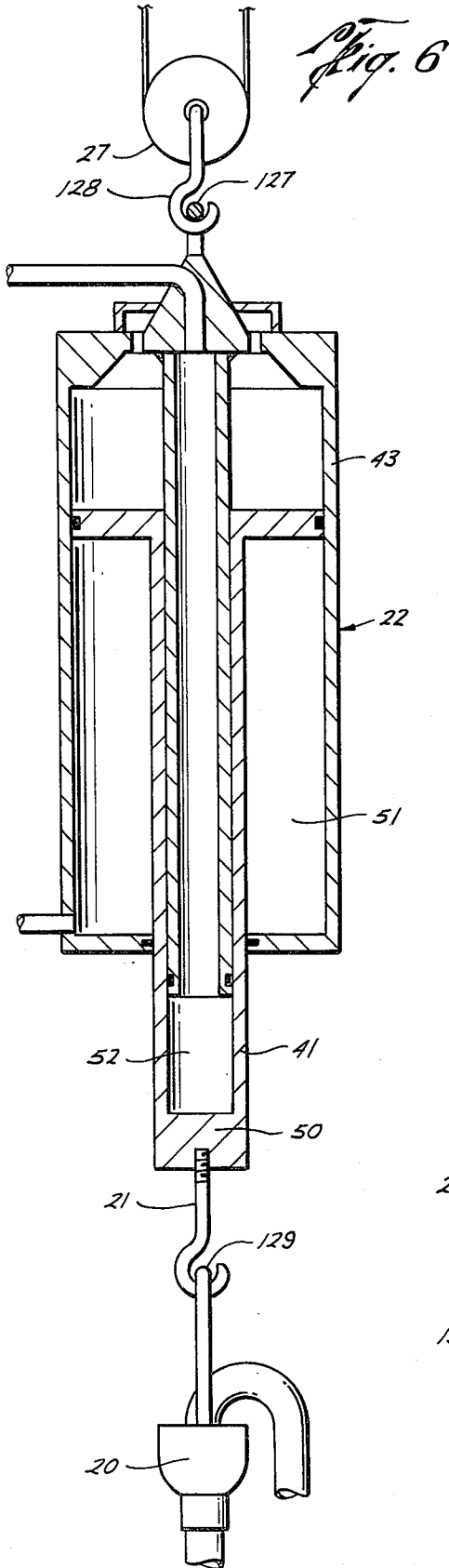
38 Claims, 10 Drawing Figures











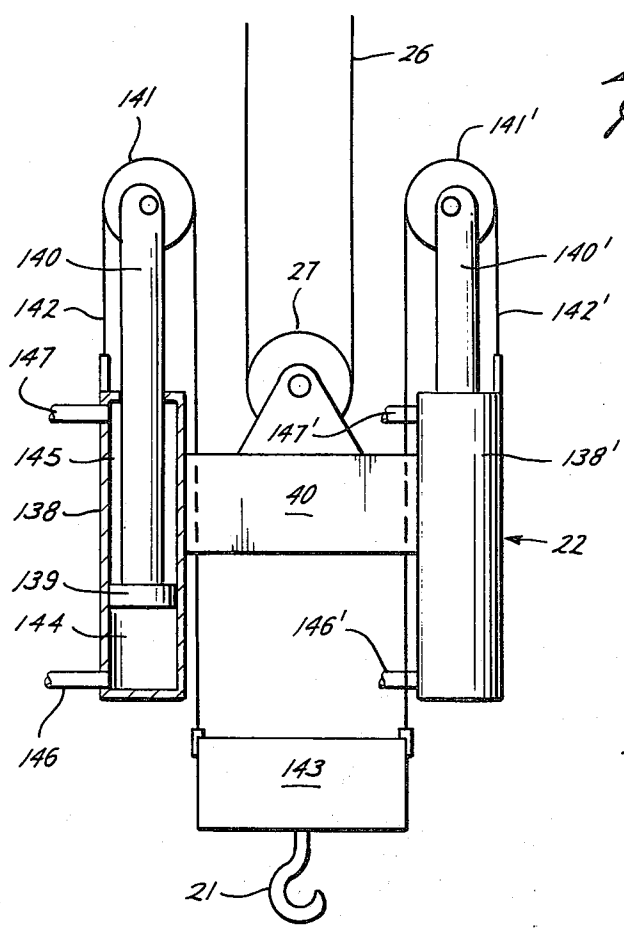


Fig. 9

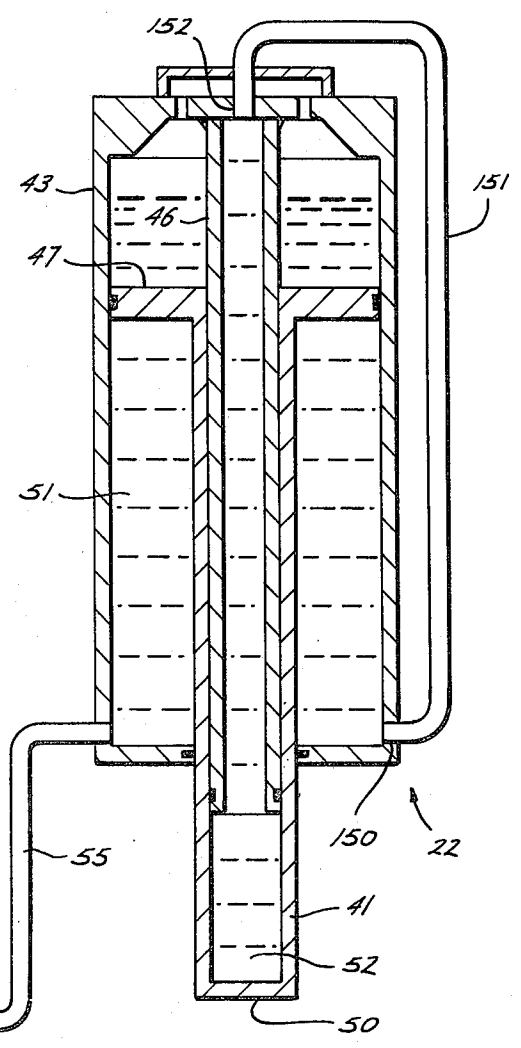


Fig. 10

MOTION COMPENSATION AND/OR WEIGHT CONTROL SYSTEM

BACKGROUND OF THE INVENTION

This invention relates to a motion compensation and/or weight control system for an assembly that supports a load. This invention has particular application to a load-supporting assembly, such as an earth-boring assembly, mounted on a floating structure.

In the use of conventional earth-boring assemblies, it is often desirable to maintain a constant weight on a tool being used to bore into the earth. Numerous so-called "automatic driller" apparatus have been developed in an attempt to solve this problem. This constant weight problem is intensified when the hole being bored in the earth is under water and the earth-boring assembly is mounted on a floating structure. As the structure moves upwardly and downwardly with the waves, the weight applied to the tool through the drill string or the like is alternately decreased (sometimes to the extent of lifting the tool from contact with the earth) and increased (sometimes to the extent of damaging the tool or the drill string).

Other problems encountered in utilizing an earth-boring assembly or other load-supporting assembly mounted on a floating structure are to maintain the tool or load suspended on a drill string or the like at a constant location and to move the tool or load upwardly or downwardly at selected velocities. For example, it is often desirable to maintain a cutting tool inside a well casing at a constant location intermediate its length. And it is often desirable to land smoothly a blowout preventer apparatus on a subsurface wellhead. However, the upward and downward movement of the floating structure supporting the earth-boring assembly may cause the cutting tool to move about vertically inside the well casing or cause the blowout preventer to slam into the wellhead.

Various attempts have been made to stabilize a floating structure supporting an earth-boring assembly, such as are exemplified in the U.S. Pat. No. 3,490,406. Various attempts have been made to develop slip joints or compensator means in the drill string or conductor itself, such as are exemplified in the U.S. Pat. No. 3,353,851 and No. 3,319,981.

Additionally, various attempts have been made to develop a motion compensation or weight control system to be secured between the load and the assembly supporting the load. Illustrative of such efforts are the following U.S. Pat. Nos.: 3,804,183; 3,793,835; 3,721,293; 3,718,316; 3,714,995; Re. 27,261; 3,469,820; 3,309,065; 3,285,574; 3,259,371; 3,158,208; 3,158,206; 3,151,686; 2,945,677; and 2,945,676. For one reason or another, each of the prior motion compensation systems is disadvantageous or undesirable.

Prior efforts to construct a motion compensation and/or weight control system to be mounted between the supporting assembly and its load have recognized the need for some sort of expansible and contractible mechanism which is capable of generating uniform forces at any point of its expansion and contraction range. Generally, a sturdy, telescoping, piston and cylinder assembly has been chosen to provide the expansible and contractible movement. However, great difficulty has been experienced in constructing a practical motion compensation and/or weight control system

wherein the piston and cylinder assembly provides uniform forces throughout its entire movement range.

Numerous of such prior systems have attempted to operate a piston and cylinder assembly so that it generates uniform forces throughout its movement range by supplying fluid at a predetermined pressure to the piston and cylinder assembly. This contained fluid generally is a gas alone or a hydraulic-pneumatic combination in which a gas is maintained in an accumulator bank at a predetermined pressure and the pressure of the gas is transferred to a hydraulic fluid which in turn is supplied to the piston and cylinder assembly. These systems for controlling the movement of the piston and cylinder assembly are commonly referred to as "passive" systems because there is no pump or the like actively forcing fluid into the piston and cylinder assembly.

Unfortunately, no practical passive system has been constructed which will provide true motion compensation and/or weight control. This is because the volume of the contained gas changes as the gas or the hydraulic fluid in the pneumatic-hydraulic combination moves in and out of the piston and cylinder assembly responsive to the longitudinal movement of the piston. In accordance with Charles' law (assuming the temperature of the fluid is relatively constant), this change in the volume of the contained gas produces a change in its pressure. And this change in the pressure of the gas results in a corresponding change in the pressure of the hydraulic fluid in the piston and cylinder assembly, which in turn produces erroneous motion compensation and/or weight control.

Of course, the magnitude of this pressure variation can be decreased by increasing the volume of the accumulator bank containing the pressurized gas. But this has practical limitations. Indeed, even the largest practical accumulator system being utilized today to control passively a heavy-duty motion compensation and/or weight control system, still produces approximately a plus or minus four percent pressure error as the piston moves throughout its stroke. And it is not uncommon in the smaller passively operated systems for the pressure error to increase up to approximately plus or minus eight percent. Moreover, the friction of the fluid moving into and out of the cylinder and its attendant components, the friction of the packing between the piston and the cylinder, and the inertia of the piston, cause additional pressure losses. These combined pressure losses in a passively operated system can easily equal approximately plus or minus ten percent.

Other such prior systems have attempted to provide accurate motion compensation and/or weight control by affirmatively pumping or otherwise forcing hydraulic fluid into and regulating its flow out of the piston and cylinder assembly to maintain a constant pressure in the cylinder at all times irrespective of the longitudinal position of the piston within the cylinder. These systems are commonly called "active" systems. However, these active systems have practical drawbacks. Motion compensation and/or weight control systems to be used to support heavy loads are quite massive. It is not uncommon for there to be two cylinders, each of which is in excess of 20 feet in length and in excess of 100 square inches in cross-sectional area. As the piston moves longitudinally within the cylinder, a vast amount of hydraulic fluid must move in and out of the cylinder. To actively move such hydraulic fluid into and out of

a cylinder requires enormous horsepower and, accordingly, very large pumps. It has been found that it is simply not practical to construct a purely active motion compensation and/or weight control system for large magnitude loads.

U.S. Pat. No. 3,259,371 to Goepfert et al discloses a motion compensation system for use with a load-supporting assembly mounted on a floating structure which is a combination passive and active system. The Goepfert motion compensation system includes a linear positioning device or expansible and contractible mechanism which has coupled to one end thereof a source of constant pressure fluid and which has coupled to the other end thereof a hydraulic control valve connected to a pump and to a source of hydraulic fluid. The control valve is operated by electrical signals generated by a controller responsive to the linear position of the floating structure relative to the earth and the linear position of the linear positioning device relative to its activator rod.

Prior art motion compensation and/or weight control systems usually have operated either in a pressure mode, that is, responsive to changes in the pressure of the fluid in the expansible and contractible mechanism, or in a position mode, that is, responsive to the expansion and contraction of the expansible and contractible mechanism and the movement of the floating structure relative to the earth. Depending upon the task to be accomplished, there are certain advantages attendant to operating either in the pressure mode or the position mode. Most of the prior art motion compensation and/or weight control systems cannot be readily switched between the pressure mode and the position mode. Additionally, those prior art motion compensation and/or weight control systems which are capable of operating in the position mode function responsive to input data indicative only of the magnitude and direction of the expansion and contraction of the expansible and contractible mechanism and of the movement of the floating structure relative to the earth.

OBJECTS OF THE INVENTION

The improved motion compensation and/or weight control system according to this invention is a combination passive and active system which overcomes the disadvantages of the purely passive systems and the purely active systems, and is an improvement over the combination passive and active system disclosed in Goepfert et al U.S. Pat. No. 3,259,371.

The improved motion compensation and/or weight control system according to this invention may be generally described as a system mounted on a load-supporting assembly for supporting a load which is movable relative to the load-supporting assembly. The system includes an improved expansible and contractible mechanism which preferably depends from a traveling block, drill head or the like mounted in a derrick, tower or the like. The load to be supported then depends from the improved expansible and contractible mechanism. The improved expansible and contractible mechanism according to this invention includes at least one primary piston and cylinder assembly, preferably passively operated, providing forces at least sufficient to support the load. The improved expansible and contractible mechanism also includes at least one secondary piston and cylinder assembly, preferably actively

operated, providing forces opposing the forces of the primary piston and cylinder assembly.

The motion compensation and/or weight control system according to this invention can be operated in either the pressure mode or the position mode. When the system is operated in the position mode, hydraulic fluid is actively supplied to and withdrawn from the secondary piston and cylinder assembly responsive not only to the magnitude and direction of the expansion and contraction of the expansible and contractible mechanism and of the movement of the floating structure relative to the earth, but also to the velocity of such expansion and contraction and such movement.

It is an object, therefore, of this invention to provide an improved motion compensation and/or weight control system which overcomes the disadvantages and undesirable characteristics of prior motion compensation and/or weight control systems.

It is an object of this invention to provide an improved motion compensation and/or weight control system for a load-supporting assembly mounted on a floating structure, which system is more accurate than prior systems in compensating for the movement of the floating structure and/or in maintaining a constant weight on a tool supported by the load-supporting device.

It is an object of this invention to provide an improved motion compensation and/or weight control system for a load-supporting assembly which, when used with a cable and a traveling block, provides an expansible and contractible mechanism between the traveling block and the load and thus reduces the length of the piston stroke required by prior systems having an expansible and contractible mechanism secured to the cable in the dead-end thereof.

It is an object of this invention to provide an improved motion compensation and/or weight control system which includes an improved expansible and contractible mechanism comprising a passively operated piston and cylinder assembly providing forces supporting the load and an opposing actively operating piston and cylinder assembly providing biasing forces.

It is an object of this invention to provide an improved motion compensation and/or weight control system which can be operated either in a position mode or a pressure mode.

It is an object of this invention to provide an improved motion compensation and/or weight control system which, when operated in the position mode, functions responsive not only to input data indicative of the direction and magnitude of the expansion and contraction of the expansible and contractible mechanism and of the movement of the floating structure relative to the earth, but also responsive to input data indicative of the velocity of such expansion and contraction and such movement.

It is an object of this invention to provide an improved motion compensation and/or weight control system for use with a block and cable earth-boring assembly, which system employs an expansible and contractible mechanism which may be easily removed from active use in the earth-boring assembly during tripping.

This invention possesses many other advantages and has other objects which may be made more clearly apparent from the consideration of the forms in which it may be embodied. Several embodiments of the inven-

tion are shown in the drawings accompanying and forming part of the present specification. These embodiments of the invention will now be described in detail for the purpose of illustrating the general principles of the invention; but it is to be understood that such detailed descriptions are not to be taken in a limiting sense.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring to the drawings in which like numerals represent like parts:

FIG. 1 is a diagrammatic view of an embodiment of a motion compensation and/or weight control system according to this invention in association with an earth-boring assembly mounted on a floating structure for drilling a well hole beneath a body of water.

FIG. 2 is a front elevational view, with certain parts shown in longitudinal section of the expansible and contractible mechanism of the system disclosed in FIG. 1 in a partially telescoped position, and with the components of the system for passively supplying hydraulic fluid and for actively supplying hydraulic fluid to the expansible and contractible mechanism being shown schematically.

FIG. 3 is a graph depicting with respect to time the typical vertical movement of a floating drilling rig and the typical vertical movement of the piston rod of the expansible and contractible mechanism relative to its outer cylinder.

FIG. 4 is a schematic and block diagram of a preferred arrangement of the electrical components of the control means in the active portion of the system.

FIG. 5 is a front elevational view, with certain parts shown in longitudinal section, of an alternate component for actively supplying hydraulic fluid to the expansible and contractible mechanism disclosed in FIG. 2.

FIG. 6 is a front elevational view, with certain parts shown in longitudinal section, of an alternate expansible and contractible mechanism according to this invention.

FIG. 7 is a diagrammatic view of an alternate embodiment of the motion compensation and/or weight control system according to this invention in association with an earth-boring apparatus having a hydraulically supported drill head and mounted on a floating structure.

FIG. 8 is a front elevational view, with certain parts shown in longitudinal section, of still another embodiment of an expansible and contractible mechanism according to this invention.

FIG. 9 is a front elevational view, with certain parts shown in longitudinal section, of still another embodiment of an expansible and contractible mechanism according to this invention.

FIG. 10 is a front elevation view, with certain parts shown in longitudinal section, of still another embodiment of an expansible and contractible mechanism according to this invention, with the attendant component for passively supplying hydraulic fluid thereto shown schematically.

DESCRIPTION OF PREFERRED EMBODIMENTS OF INVENTION

A. Motion compensation and/or weight control system utilized with a floating, block and cable, earth-boring assembly

1. Schematic description of earth-boring assembly and system

FIG. 1 illustrates a preferred embodiment of the motion compensation and/or weight control system according to this invention utilized in connection with an earth-boring assembly having cables and a traveling block and mounted on a structure floating in water. The earth-boring assembly is illustrated drilling a vertical well hole 11 into a sub-aqueous seabed 12. The floating structure 13 is suitably anchored (not shown) against excessive lateral displacement for the purpose of holding the drill string 14 in centered relation with respect to the well hole. A drill bit 15 is secured to the lower end of the drill string 14 and is in contact with the earth. A marine riser 16 extends from the wellhead 17 at the sea floor upwardly to a location adjacent the floating structure 13.

The upper portion of the drill string 14 is secured to a kelly 18 passing through a rotary table 19. The upper end of the kelly is secured to a swivel 20 which is in turn suspended from a hook 21 connected to the lower portion of the expansible and contractible mechanism 22 of the improved motion compensating and/or weight control system according to this invention. A mud line 23 is connected to the swivel.

The earth-boring assembly illustrated in FIG. 1 employs a derrick 24 having a crown block 25 secured at the top thereof. Depending by cable 26 from the crown block 25 is traveling block 27. Cable 26 is dead-ended to the floating structure 13 at a selected point 28, extended upwardly and suitably reeved about crown block 25 and traveling block 27, then extended downwardly to the drawworks 29. The drawworks 29 winds-in or winds-out the cable 26 to raise and lower the traveling block 27. A weight indicator 30 preferably is coupled into the cable 26 at a selected location, such as adjacent the dead-end thereof.

The motion compensation and/or weight control system according to this invention utilizes an expansible and contractible mechanism 22 to provide a desired telescoping action whereby selected movement of the load relative to the floating structure can be effected or, if the load is in contact with the earth, a certain pressure can be maintained between the load and the earth. The expansible and contractible mechanism 22 of the motion compensating and/or weight control system according to this invention is shown in FIG. 1 secured or interposed between traveling block 27 and hook 21. Thus, the load—comprising swivel 20, kelly 18, drill string 14, drill bit 15, and other attendant apparatus secured thereto—is supported directly by the expansible and contractible mechanism of the motion compensation and weight mechanism 22. The weight of the load hooked to or supported by the expansible and contractible mechanism 22 is referred to as the "hook load." By locating the expansible and contractible mechanism 22 between the traveling block and the load, rather than between the dead-end of cable 26 and the floating structure 13, the required amount of expansion and contraction of the mechanism 22 is reduced. For example, assuming that the crown block and traveling block provided a ten to one reduction in the movement of the cable 26, an expansible and contractible mechanism mounted between the floating structure 13 and the dead-end of the cable 26 would have to expand and contract a distance of forty feet to move the load four feet. Additionally, an expansible

and contractible mechanism mounted above the crown block or on the floating structure must contend with the friction forces generated by the reversal of the crown block and the traveling block as the cable is reeved in and out during the compensation cycle.

Mounted on the floating structure 13 is an oil/air interface tank 35, a bank 36 of air accumulator tanks, and a means 37 for actively supplying hydraulic fluid. As will hereafter be explained, the oil/air interface tank 35 and the bank 36 of air accumulator tanks function to passively introduce and withdraw hydraulic fluid to and from the expansible and contractible mechanism 22 and means 37 functions to actively introduce and withdraw hydraulic fluid to and from the expansible and contractible mechanism 22. Also mounted on the floating structure is a rotatable drum 38 which, as will be hereinafter explained, is employed in determining the vertical position of the floating structure with respect to the seabed.

As illustrated in FIG. 2, a preferred embodiment of the expansible and contractible mechanism 22 according to this invention comprises two identical piston and cylinder assemblies 39 and 39'. Each of the piston and cylinder assemblies 39 and 39' is secured to a support member 40, which in turn is secured to the traveling block 27. Movable longitudinally within each of the cylinders 39 and 39' is a piston rod 41 and 41', respectively. Piston rods 41 and 41' are secured to a second support member 42, from which depends the hook 21.

In this embodiment of the motion compensation and/or weight control system according to this invention, each of the two piston and cylinder assemblies of the expansible and contractible mechanism 22 extends upwardly along the side of the traveling block. For a selected size of expansible and contractible mechanism, this reduces the height beneath the derrick of the total mechanism. However, the expansible and contractible mechanism of the improved motion compensation and/or weight control system according to this invention is not limited to a piston and cylinder assembly secured to either side of the traveling block. Indeed, it can comprise more than two cylinder and piston assemblies surrounding a traveling block, one cylinder and piston assembly depending from the traveling block (as hereinafter described), or other configurations (some of which are hereinafter described).

Each of the piston and cylinder assemblies 39 and 39' (only piston and cylinder assembly 39 will be described fully hereinafter) in this embodiment of this invention comprises an outer, primary cylinder 43 having end plates 44 and 45. Attached to the upper end plate 44 of outer cylinder 43 and depending therefrom is an inner cylinder 46 disposed concentrically within the outer cylinder 43. Inner cylinder 46 preferably extends the full length of outer cylinder 43 and protrudes a slight distance beyond the lower end plate 45 of outer cylinder 43. The piston rod 41 previously referred to is cylindrical and hollow, and is slidably disposed around the inner cylinder 46. A first piston 47 is secured to the upper end of the piston rod 41 within the annular chamber formed between the inner cylinder 46 and the outer cylinder 43. The first piston 47 is slidable in such annular chamber and carries a suitable seal ring 48 for slidably sealing against the outer cylinder wall. The inner cylinder 46 carries a suitable seal ring 49 for slidably sealing against the slidable piston rod 41. The

lower end of the piston rod 41 comprises a second piston 50.

The annular chamber formed between the lower end plate 45, outer cylinder 43, piston rod 41, and first piston 47 comprises a primary chamber 51, sometimes referred to as the passive chamber. The chamber formed within the upper end plate 44, inner cylinder 46, hollow piston rod 41, and the second piston 50 comprises a secondary chamber 52, sometimes referred to as the active chamber. The annular chamber formed between the upper end plate 44, first piston 47, and inner cylinder 46 comprises a deceleration chamber 53.

A port 54 is provided in the lower part of outer cylinder 43 in fluid communication with passive chamber 51. A conduit 55 provides fluid communication from the port 54 to the oil/air interface tank 35. The oil/air interface tank 35 is in fluid communication through conduit 56 with the bank 36 of air accumulator tanks. Thus, the bank of air accumulator tanks and the oil/air interface tank provide the standard pneumatic/hydraulic system for passively supplying and receiving pressurized hydraulic fluid to and from the primary chamber 51. In fluid communication with the hydraulic fluid in primary chamber 51 is a pressure transducer 57 which determines the pressure of the hydraulic fluid and generates an electrical signal proportional thereto.

A port 58 is provided through the upper end plates and into each of the secondary or active chambers 52 and 52'. A conduit 59 places active chambers 52 and 52' in fluid communication with a means 37 for introducing and withdrawing hydraulic fluid into and from active chambers 52 and 52'. A pressure transducer 60 such as a Tyco Instruments Model AF 3000, is in communication with the active hydraulic fluid being supplied to active chambers 52 and 52'. Such pressure transducer determines the pressure of the fluid in the active chambers and generates a signal proportional thereto.

A preferred means for actively introducing and withdrawing hydraulic fluid into and from secondary chambers 52 and 52' is illustrated within the dashed lines 37 in FIG. 2. Conduit 59 is in fluid communication with a pump 61. Pump 61 is in fluid communication through conduit 62 with a sump 63 in which hydraulic fluid is maintained. Pump 61 may be any of various commercially available devices, but preferably is a variable volume, bidirectional, over-center pump such as manufactured by Von Roll, Ltd. of Switzerland, Rex Roth, Sunstrand, or Dynapower. In the preferred pump, the direction in which hydraulic fluid is pumped and the volume of hydraulic fluid so pumped is controlled by the position of the yoke of the pump. The position of the yoke of the pump is controlled by a servo valve 64 such as is well known to those skilled in the art. The operation of the servo valve is controlled by electrical signals supplied thereto from control means 65. Control means 65 operates, as will hereafter be explained, responsive to a feedback signal from servo valve 64 and input signals supplied to the control means 65 which vary depending upon whether the system is operated in the tied-to-ground mode or the pressure mode.

Other types of pumps and arrangements of servo valves may be utilized rather than the variable-volume, bidirectional pump. For example, Goepfert et al U.S. Pat. No. 3,259,371 discloses a unidirectional pump coupled to a servo valve which varies the direction of flow of the

drilling fluid back and forth between a cylinder and a sump.

As illustrated in FIG. 2, in each of the piston and cylinder assemblies there is an annular chamber 53 between the upper end plate 44 of the outer cylinder 43, the inner cylinder 46, and the first piston 47. This annular chamber 53 is a deceleration chamber. It preferably contains a selected amount of hydraulic fluid. The upper end plate 44 of outer cylinder 43 preferably has inclined shoulders 66 providing a tapered, truncated surface leading to one or more orifices 67 which communicate with an exterior chamber 68. In the case of a sudden upward movement of piston rod 41, such as may be caused by the parting of the load secured to hook 21, the hydraulic fluid contained in deceleration chamber 53 will slow the upward movement of the first piston 47 as the fluid flows through the restrictive orifices 67 into the exterior chamber 68. Additionally, as will be hereinafter explained, the hydraulic fluid contained in the active chamber 52 will oppose the upward movement of piston rod 41 and thus aid in the deceleration.

FIG. 3 illustrates graphically with respect to time the typical vertical movement of the floating structure 13 relative to the wellhead 17. The vertical movement of the floating structure responsive to normal wave motion produces a graph 71 which is sinusoidal. The floating structure 13 is farthest from the wellhead 17 at point in time 72 when it is on the crest of the wave and is closest to the wellhead 17 at point in time 73 when it is in the trough of the wave. As shown in FIG. 3, the floating structure is experiencing twelve foot heaves, that is, plus and minus six feet from the center position of the heave. As the floating structure 13 moves, the outer cylinders 43 and 43' of the expansible and contractible mechanism 22 will likewise move (assuming the drawworks 29 is locked). In order to obtain proper motion compensation and/or weight control of the load, the piston rods 41 and 41' should move relative to the outer cylinders 43 and 43' as the floating structure heaves. When the system is operated such that the load remains stationary vertically with respect to the earth, the piston rods 41 and 41' should move relative to the outer cylinders 43 and 43' in the direction opposite to the floating structure at a distance and at a velocity equal to the movement of the floating structure, as illustrated by the dashed sinusoidal line 74. However, as will become apparent hereinafter, when the system is operated such that a selected weight is maintained on a tool in contact with the earth, the movement of the piston rods relative to the outer cylinders will not necessarily "track" the movement of the floating structure.

As will be hereinafter explained, the various sensors utilized to produce input data for the control means 65 will vary depending upon the mode in which the system is operated. The pressure transducers 57 and 60 previously described constitute one set of sensors for generating input signals. The other set of sensors comprises means for determining the position of the piston rods 41 and 41' relative to the outer cylinders 43 and 43', means for determining the velocity of the movement of the piston rods 41 and 41' relative to the outer cylinders 43 and 43', means for determining the position of the floating structure 13 relative to the wellhead 17, and means for determining the velocity of the movement of the floating structure 13 relative to the well-

head 17. These means may be of numerous devices well known to those skilled in the art. However, as illustrated in FIG. 2, the means for determining the position of the piston rods relative to the outer cylinders preferably comprises a position transducer 75 secured between the first support member 40 and the second support member 42. The position transducer 75, such as a Beckman potentiometer, a Bourns potentiometer, or a Lockheed Electronics position transducer, preferably comprises a spring-loaded rotary element 76 secured to the first support member and a line or cable 77 secured to the second support member 42. Linear movement of the second support member 42 relative to the first support member 40 causes the cable 77 to wind onto and unwind from the rotary element 76, thereby rotating the rotary element. The position transducer 75 generates an electrical signal proportional to the direction and magnitude of the rotation of the rotary element, which electrical signal is coupled via a conductor (not shown) to the control means 65. The means for determining the direction and the velocity of the movement of the piston rods relative to the outer cylinders preferably comprises a velocity transducer 78, such as a Servotek DC Tachometer or other commercially available device, also secured between the first and second support members. Preferably the velocity transducer 78 comprises a spring-loaded rotary member secured to the first support member and a line or cable secured to the second support member. Linear movement of the two support members relative to each other causes the cable to wind onto and unwind from the rotary element. The velocity transducer 78 generates an electrical signal proportional to the direction and velocity of the rotation of the rotary element, which electrical signal is coupled to the control means 65 via conductor (not shown).

There are many devices well known to those skilled in the art which may be used to monitor the vertical position of the floating structure relative to the wellhead. Dynamically positioned vessels are being constructed today in which sonar, accelerometers, lasers, and other sophisticated electronics are utilized to monitor the position of the vessel and to generate data proportional thereto. The means for determining the linear position of the floating structure relative to the wellhead preferably comprises, as illustrated in FIG. 1, a cable 79 secured to the marine riser 20, which in turn is secured to the wellhead on the sea floor. Alternately, the cable 79 could be connected to the guidelanes or directly to the wellhead. The cable 79 is reeved around the rotatable drum 38. Drum 38 maintains a constant tension on the cable 79 and winds or unwinds the cable responsive to the movement of the floating structure 13 relative to the wellhead. A position transducer 80, such as previously described with respect to position transducer 75 or one of the numerous shaft encoders manufactured by Astrosystems, Inc. and well known in the art, is attached to drum 38. The position transducer produces an electrical signal proportional to the direction and magnitude of the rotation of such drum 38, which signal is coupled to the control means 65 via conductor (not shown). The means for determining the direction and the velocity of the movement of the floating structure relative to the wellhead preferably comprises a rotatable velocity transducer 81, such as is well known to those skilled in the art, attached to drum 38. The velocity transducer 81 produces an electrical signal propor-

tional to the direction and velocity of rotation of the drum 38, which signal is coupled to the control means 65 via conductor (not shown).

An optional sensor means comprises another position indicating device (not shown) associated with the draw works 29 or with the crown block 25 for indicating the amount of cable 26 wound-in or wound-out by the draw works 29. Such position indicating device generates an electrical signal proportional to the length of the cable 26 wound-in or wound-out from the draw works, which signal may be utilized to determine the position of the traveling block 27 relative to the floating structure 13. A typical position transducer would be the Beckman potentiometer, Bourns potentiometer, or Lockheed Electronics position transducers.

When the improved motion compensation and/or weight control system according to this invention illustrated in FIGS. 1 and 2 is operated in the position mode, the control means 65 functions responsive to the electrical signals generated by position transducer 75, velocity transducer 78, position transducer 80, and velocity transducer 81, to cause servo valve 64 to operate pump 61 such that hydraulic fluid is supplied to and withdrawn from the active chambers 52 and 52'.

At first, it was believed that in the position mode, effective motion compensation and/or weight control could be accomplished if the control means 65 functioned responsive to only the electrical signals generated by position transducer 75 and the position transducer 80. However, it was determined empirically that, in the position mode, the system operated better if the control means was provided additional input data. For example, as illustrated in FIG. 3, if at point in time 82 the electrical signals from position transducers 75 and 80 inform control means 65 that sufficient hydraulic fluid has been withdrawn from the active chambers 52 and 52' to compensate for the error in the passive portion of the system as the floating structure 13 moves downwardly, then the control means 65 will cause the servo valve to operate pump 61 such that at point in time 82 no additional hydraulic fluid is either withdrawn from or supplied to the active chambers 52 and 52'. Thereafter, as the floating structure 13 moves further downward, such as at point in time 83, additional hydraulic fluid must be withdrawn from the active chambers 52 and 52' to compensate for the additional error in the passive portion of the system. However, since no hydraulic fluid was being withdrawn from the active chambers 52 and 52' at point in time 83, error in the motion compensation and/or weight control will result during the time interval between point in time 82 and the point in time that the proper amount of hydraulic fluid is withdrawn from the active chambers 52 and 52'. And then the control means 65 will cause servo valve 64 to operate pump 61 such that an excess of hydraulic fluid is withdrawn from active chambers 52 and 52' so that the system can "catch up." As a result, rather than the piston rods 41 and 41' smoothly moving in the direction opposite to the floating structure a distance equal to the movement of the floating structure as shown by the dashed line 74, the piston rods will oscillate as illustrated by the dotted line 84.

It has been discovered that such error in the motion compensation and/or weight control system operated in the position mode can be substantially reduced if the control means 65 functions responsive primarily to the data provided by the velocity transducer 78 and the ve-

locity transducer 81. Accordingly it is preferred that the control means 65 cause pump 61 to supply and withdraw hydraulic fluid to and from the active chambers in accordance with the following equation:

$$(1) Q = k_1(Vs) + k_2(Ve) + k_3(Le)$$

wherein Q is the volume of the hydraulic fluid supplied to or withdrawn from the active chambers, k_1 is a constant, Vs is the direction and velocity of the movement of the floating structure, k_2 is a constant, Ve is the difference between the direction and velocity of the movement of the floating structure and the direction and velocity of the movement of the piston rods 41 and 41' (herein sometimes referred to as "velocity error"), k_3 is a constant, and Le is the difference in the position of the floating structure relative to the wellhead and the position of the piston rods relative to the outer cylinders (herein sometimes referred to as "position error"). Although it has been determined empirically that effective motion compensation and/or weight control can be obtained when the control means operates responsive only to velocity data, it is still desirable to utilize position data to account for drift in the system such as may be caused by loss of hydraulic fluid and the like.

2. Detailed description of electrical components of active portion of system

FIG. 4 illustrates partially in schematic and partially in block diagram a preferred arrangement of the electrical components comprising the control means 65. The portion of such electrical components utilized when the system is operated in the position mode is as follows. Position transducer 80 generates an electrical signal proportional to the linear position of the floating structure relative to the wellhead. This electrical signal is added to an electrical signal generated by potentiometer 85, which is adjusted to a magnitude proportional to the tide. This combined electrical signal is coupled to the input of an operational amplifier 86, such as a type 741. Also coupled to the input of amplifier 86 is an electrical signal generated by position transducer 75 which is proportional to the linear position of the piston rods 41 and 41' relative to the outer cylinders 43 and 43'. Amplifier 86 functions to compare the two electrical signals supplied to its input and generate an electrical signal proportional to the difference therebetween. This electrical signal generated by amplifier 86 is proportional to the position error.

Velocity transducer 78 generates an electrical signal proportional to the direction and velocity of the movement of the piston rods relative to the outer cylinders. Velocity transducer 81 generates an electrical signal proportional to the direction and velocity of the movement of the floating structure relative to the wellhead. These two electrical signals are coupled to an operational amplifier 87 which functions to compare them and generate an electrical signal proportional thereto. The electrical signal generated by amplifier 87 is proportional to the velocity error.

The position error signal generated by amplifier 86 and the velocity error signal generated by amplifier 87 are coupled to an operational amplifier 88 which functions to compare them and generate an electrical signal proportional to their sum. The electrical signal generated by amplifier 88 and the velocity signal generated by transducer 81 are coupled to operational amplifier 89 which functions to compare the two signals and gen-

erate an electrical signal proportional to their sum. The electrical signal generated by amplifier 89 is proportional to the volume of hydraulic fluid which should be supplied to or withdrawn from the active chambers 52 and 52' to obtain substantially error-free motion compensation when the system is operated in the position mode.

The electrical signal generated by amplifier 89 is coupled through switch 90 to the input of a conversion means 91. Also coupled to the input of conversion means 91 is an electrical signal generated by tachometer 92 which is proportional to the speed of the motor (not shown) driving pump 61. The conversion means 91, any of numerous devices well known to those skilled in the art, functions to convert the input electrical signal which is proportional to the volume of hydraulic fluid to be supplied to or withdrawn from the active chambers, into an electrical signal which is inversely proportional to the speed of the pump 61. The output of conversion means 91 is coupled to the input of non-linear compensation means 93 which functions to alter the electrical signal to compensate for any non-linearity in the system. The output of non-linear compensation means 93 is coupled to the input of an operational amplifier 94. Also coupled to the input of amplifier 94 is a feedback electrical signal generated by linear variable differential transformer (LVDT) 95 which functions to transduce the position of the yoke of pump 61 into an electrical signal proportional thereto. The amplifier 94 functions to compare the two electrical signals supplied to its input and generate an electrical signal proportional to the difference therebetween. The electrical signal generated by amplifier 94 is coupled to servo driver 96 which functions to supply the desired electrical signals to servo valve 64. Servo valve 64 is mechanically connected to the yoke of pump 61.

Once the specifications of a system are determined, the desired magnitudes of the constants k_1 , k_2 , and k_3 in formula (1), as well as the various resistances, capacitances, inductances to be added to the circuitry and adjustments to the amplifiers to incorporate the constants k_1 , k_2 , and k_3 , are easily designable by those skilled in the art with only a routine amount of experimentation.

In the pressure mode, the control means 65 functions responsive to the electrical signals generated by the pressure transducer 57 and the pressure transducer 60 to cause servo valve 64 to operate pump 61 such that hydraulic fluid is supplied to and from the active chambers 52 and 52'. It has been discovered empirically that when the system is operated in the pressure mode, there is no need to monitor the velocity of the movement of the floating structure relative to the wellhead or the velocity of the movement of the piston rods relative to the outer cylinders. Proper weight control may be obtained simply by monitoring the pressure of the hydraulic fluid in the passive chambers and the pressure of the hydraulic fluid in the active chambers. Accordingly, it is preferred that the control means 65 cause pump 61 to supply and withdraw hydraulic fluid to and from the active chambers in accordance with the following equation:

$$(2) Q = (P_1 A_1 - P_2 A_2) - K$$

wherein Q is the volume of the hydraulic fluid supplied to or withdrawn from the active chambers, P_1 is the pressure of the hydraulic fluid in the passive chambers, A_1 is the effective cross-sectional area of the passive

chambers, P_2 is the pressure of the hydraulic fluid in the active chambers, A_2 is the effective cross-sectional area of the active chambers, and K is the desired hook load.

It is believed that the reason velocity data is not needed when the system is operated in the pressure mode, but is desirable when the system is operated in the position mode, is that the system has a much faster response to change when operated in the pressure mode. In the pressure mode, the primary parameter—pressure—is being monitored and acted upon. In the position mode, a secondary parameter—position—is being monitored and acted upon (position is a secondary parameter because it changes after there has been a change in the pressure of the hydraulic fluid.)

Referring again to FIG. 4, the portion of the preferred electrical components of the control means 65 utilized in the operation of the system in the pressure mode will be described. Pressure transducer 57 transduces the pressure of the hydraulic fluid in the passive chambers 51 into an electrical signal proportional thereto. Pressure transducer 60 transduces the pressure of the hydraulic fluid in the active chambers 52 into an electrical signal proportional thereto. These two electrical signals are coupled to the input of an operational amplifier 100, such as a 741, which functions to compare them and generate an electrical signal responsive to the difference therebetween. The output of amplifier 100 is coupled to the input of operational amplifier 101. Also coupled to the input of amplifier 101 is an electrical signal generated by potentiometer 102 which is proportional to the desired hook load. Amplifier 101 functions to compare the two electrical signals supplied to its input and generate an electrical signal proportional to the difference therebetween. The electrical signal generated by amplifier 101 is coupled through switch 103 to the input of the conversion means 91. The conversion means 91 and the remaining components acting responsive to the output of conversion means 91 are as heretofore explained.

Once the specifications of the system are determined, the various resistances, capacitances and inductances to be added to the circuitry and the adjustments to the operational amplifiers to take into account the areas A_1 and A_2 in formula (2) are easily designable by those skilled in the art with only a routine amount of experimentation.

The other preferred electrical components of the control means 65 illustrated in FIG. 4 will now be described. Preferably, the electrical signal generated by position transducer 75 is coupled to the input of operational amplifier. Also coupled to the input of amplifier 104 is an electrical signal generated by potentiometer 106 which is proportional to a selected, desired linear position of the piston rods 41 relative to the outer cylinders 43. Preferably, potentiometer 106 is adjusted to generate an electrical signal proportional to the position of the piston rods 41 either at the center of their stroke or at the top of their stroke. Amplifier 104 functions to compare the two electrical signals supplied to its input and generate an electrical signal proportional to the difference therebetween. The electrical signal generated by amplifier 104 is coupled through switch 107 to the conversion means 91. When this portion of the circuitry is utilized, switch 107 is closed and switches 90 and 103 are opened. Amplifier 104 then generates the necessary electrical signal to cause pump 61 to supply or withdraw hydraulic fluid to and from

the active chambers such that, irrespective of the movement of the floating structure or any losses in the system, the piston rods remain at the selected, desired position, such as, at the center of their stroke or at the top of their stroke.

Coupled to the output of amplifier 86 is an operational amplifier 109. Coupled to the other input of such amplifier 109 is an electrical signal generated by potentiometer 110, which is adjusted to a selected magnitude. Amplifier 109 functions to compare the two electrical signals supplied to its input and generate a logic signal responsive thereto. Preferably, the potentiometer 110 is adjusted whereby the logic signal generated by amplifier 109 indicates whether the position of the piston rods relative to the center of their stroke equals the position of the floating structure relative to the center of its range of heave. If this portion of the circuitry is activated, when the position of the floating structure relative to the center of its range of heave equals the position of the piston rods relative to the center of their stroke, amplifier 109 generates a logic signal which causes switch 90 to close and switches 103 and 107 to open. The system then operates in the position mode.

Coupled to the output of amplifier 101 is an operational amplifier 111. Also coupled to the input of amplifier 111 is an electrical signal generated by potentiometer 112, which is adjusted to a preselected magnitude. Amplifier 111 functions to compare the two electrical signals supplied to its input and generate a logic signal responsive thereto. Preferably, potentiometer 112 is adjusted whereby the logic signal generated by amplifier 111 indicates when the actual load supported by hook 21 equals the preselected hook load K in formula (2). If this portion of the circuitry is activated, when the actual load supported by the hook equals the preselected hook load, amplifier 111 generates a logic signal which causes switch 103 to close and switches 90 and 107 to open. The system then operates in the pressure mode.

3. Operation of system in position mode

The improved motion compensation and/or weight control system according to this invention preferably is operated in the position mode when it is desired to maintain a load in a selected position relative to the earth or to move a load at a selected velocity relative to the earth. By way of example assume that the earth-boring assembly illustrated in FIG. 1 is being utilized to land a 250,000 pound blowout preventer (not shown) on the wellhead 17. Assume that when the last section of drill pipe is added to the string to lower the BOP to the wellhead, the total load supported by hook 21 is 300,000 pounds. Assume that the floating structure 13 is experiencing wave heaves six feet in either direction, that is, moving through a total distance of twelve feet. Assume the movement range of the piston rods 41 and 41' inside the outer cylinders 43 and 43' is 24 feet. The air in the bank 36 of air accumulator tanks is pressurized to the magnitude necessary to move piston rods 41 and 41' to the top of or adjacent the top of their movement range. If the combined effective cross-sectional areas of the passive chambers is approximately two hundred square inches, the pressure of the air in the bank 36 of air accumulator tanks will be in the range of 1500 to 2000 pounds per square inch. The total upward force supplied by the passive portion of the system will be in the range of approximately 330,000 pounds.

The portion of the electrical circuitry in FIG. 4 relating to amplifier 104 is energized by closing switch 107 and opening switches 90 and 103. Pump 61 is thus caused to actively pump hydraulic fluid into active chambers 52 and 52' to provide a downward force opposing the force of the hydraulic fluid in the passive chambers. If the total effective cross-sectional area of the two active chambers is approximately 23 square inches, the pressure of the active fluid supplied to the active chambers will vary within the range of approximately 150 pounds per square inch to 2500 pounds per square inch. The pressure of the hydraulic fluid in the active chambers 52 and 52' is increased until the piston rods 41 and 41' have been moved downwardly to the position selected in the adjustment of potentiometer 106, preferably the mid-point of their movement range. Once the piston rods reach the midpoint of their movement range, amplifier 104 generates the necessary electrical signal to keep the piston rods at the midpoint of their movement range. As a result, the blowout preventer is thus heaving with the heaving floating structure 13.

The ratio of the effective cross-sectional area of the active chambers to the passive chambers preferably is 1:4 or less to reduce the amount of the hydraulic fluid to be moved into and out of the active chambers, thereby reducing the flow rate of the hydraulic fluid through the pump 61 and consequently the required horsepower of the pump 61. Assuming that the maximum heave in which the motion compensation and/or weight control system will operate is one that moves the floating structure 20 feet vertically in 18 seconds, the velocity of such heave can approach 5 feet per second. It has been determined that to compensate for such five foot per second movement, it may be necessary to move as much as 3100 gallons per minute of hydraulic fluid into and out of the passive chambers 51 and 51'. But if the cross-sectional area of the active chambers is one-fourth or less than that of the passive chamber, then only 730 gallons per minute maximum would have to be actively pumped into and out of the active chambers 52 and 52'.

When it is desired that the improved motion compensation and/or weight control system according to this invention operate in the position mode to maintain the load in a selected position relative to the earth, the portion of the electrical circuitry in FIG. 4 relating to amplifier 109 is energized. When the floating structure moves through the center of its range of heave (the piston rods are being held at the center of their stroke), amplifier 109 emits a logic signal which closes switch 90 and opens switch 107. Hydraulic fluid is then actively supplied to and withdrawn from the active chambers in accordance with formula (1) above. Thus, as the floating structure 13 moves upwardly, pump 61 will actively supply hydraulic fluid into active chambers 52 and 52' at the rate necessary to drive piston rods 41 and 41' downwardly to match the upward movement of the floating vessel. Downward movement of piston rods 41 and 41' of course moves first pistons 47 and 47' downwardly, thereby forcing hydraulic fluid out of the passive chambers 51 and 51' and back into oil/air interface tank 35. This compresses the air in the bank 36 of air accumulator tanks and the oil/air interface tank 35 and causes its pressure to increase. This increase in the pressure of the air in the bank 36 of air accumulator

tanks is transmitted to the hydraulic fluid in the passive chambers 51 and 51' and increases the upward forces on first pistons 47 and 47'. However, since control means 65 is operating responsive to signals representative of the movement and the velocity of the movement of the floating structure with respect to the wellhead and the movement and the velocity of the movement of piston rods 41 and 41' with respect to outer cylinders 43 and 43', the control means detects the change in the velocity of the piston rods relative to the outer cylinders as a result of the change in the pressure of the hydraulic fluid in the passive chambers and causes pump 61 to supply even more hydraulic fluid to the active chambers 52 and 52' to overcome these increased upward forces. When the floating vessel 13 reaches the apex of its upward movement, the piston rods 41 and 41' have been driven downwardly 6 feet. The pressure of the fluid in the passive chambers will have increased such that the total upward forces of the passive portion of the system may be in the range of approximately 360,000 pounds.

When the floating vessel 13 starts back downward, control means 65 causes pump 61 to commence pumping hydraulic fluid out of the active chambers 52 and 52' and back into the sump 63. Since the upward forces on the first pistons 47 and 47' are now increased to approximately 360,000 pounds due to the decrease in the volume of the air in the passive system, piston rods 47 and 47' and the 300,000 pound load depending therefrom easily and smoothly move upwardly relative to the outer cylinders 43 and 43' as the floating structure 13 moves downwardly and hydraulic fluid is pumped out of the active chambers. Pump 61 continues to withdraw hydraulic fluid from the active chambers as the piston rods 41 and 41' moves upwardly, and increases the withdrawal of such hydraulic fluid as necessary to overcome the pressure losses existing in the physical components of the system and the pressure losses attendant to the expansion of the air in the bank 36 of air accumulator tanks and the oil/air interface tank 35. Thus, as the floating vessel 13 moves upwardly and downwardly 12 feet, the blowout preventer remains stationary relative to the wellhead.

When the improved motion compensation and/or weight control system according to this invention operates in the position mode, it is quite easy to move the load upward or downward at a selected velocity relative to the earth. For example, assume it is desirable to lower the blowout preventer into the wellhead from its present stationary position about the wellhead. This is generally accomplished by causing the draw works 29 to commence unwinding cable so that the traveling block 27, the expansible and contractible mechanism 22, and the load are all lowered toward the wellhead. The control means 65 will not be cognizant of this change in the vertical reference position of the BOP and will continue to generate the necessary electrical signals such that the mechanism 22 will expand and contract to offset the heaves of the floating structure. The BOP can thus be lowered smoothly into place on the wellhead.

Although the improved motion compensation and/or weight control system according to this invention preferably is operated in the pressure mode to maintain a selected weight on a tool in contact with the earth (as will hereinafter be explained), the system may be operated in the position mode to accomplish such task. As-

sume that the hook 1 is supporting a load of 300,000 pounds comprising 15,000 feet of drill string with a drill bit on its lower end. Assume the toolpusher wishes to maintain a pressure of 50,000 pounds between the drill bit and the earth. The motion compensation and/or weight control system must therefore supply an upward force of 250,000 pounds to the load. This 250,000 pound load on the hook 21 is the hook load.

The air in the bank 36 of air accumulator tanks is pressurized to a magnitude sufficient to raise piston rods 41 and 41' to the top of their stroke or a point adjacent the top of their stroke. Pump 61 is then caused to supply hydraulic fluid into active chambers 52 and 52' sufficient to move piston rods 41 and 41' back downward to the mid-point of their strokes. Thereafter, control means 65 operates responsive to the electrical signals from transducers 81 and 78 and 80 and 75 to cause pump 61 to supply or withdraw hydraulic fluid to or from the active chambers 52 and 52' responsive to the movement of the floating structure 13 relative to the wellhead and the movement of the piston rods 41 and 41' relative to the outer cylinders 43 and 43'. The toolpusher operating the earth-boring apparatus maintains the desired 250,000 pound hook load by viewing a dead weight indicator 30 in the cable 26 and operating the drawworks 29 responsive thereto or by causing the drawworks 29 to operate automatically responsive to the dead weight indicator 30. Any vertical movement of the floating structure 13 is compensated for by the improved motion compensation and/or weight control system according to this invention as heretofore described.

4. Operation of system in pressure mode

Although the improved motion compensation and/or weight control system according to this invention preferably is operated in the position mode to maintain a tool in a selected vertical position (as explained above), the system may also be operated in the pressure mode to maintain a tool in a selected vertical position. For example, assume that the system is supporting a 300,000 pound load comprising a 250,000 pound blowout preventer (not shown) and the drill string to which the BOP is secured. Assume that this blowout preventer is being held ten feet above the wellhead. The air in the bank 36 of accumulator tanks is pressurized to the extent necessary to raise piston rods 41 and 41' the top of their strokes or a point adjacent the top of their strokes. Since the load is 300,000 pounds, the upward forces supplied by the hydraulic fluid in the passive chambers will be somewhat in excess of 300,000 pounds. Potentiometers 102 and 112 are adjusted to generate electrical signals proportional to the 300,000 pound hook load being supported. Pump 61 is caused to supply fluid into the active chamber 52 and 52' to the extent necessary to force the piston rods 41 and 41' downward, thereby increasing the pressure of the hydraulic fluid in the passive chambers and the resultant upward forces of such fluid. When the difference between the downward forces of the fluid in the active chambers and the upward forces of the fluid in the passive chambers equals the preselected hook load of 300,000 pounds as stated in formula (2), amplifier 111 generates the necessary logic signal to close switch 103 and open switches 90 and 107.

If floating vessel 13 commences to move upwardly, the blowout preventer will resist such upward motion due to gravity, its own inertia, and the water drag

against its water plane area. This will cause the piston rods **41** and **41'** to move downwardly and the pressure of the hydraulic fluid in the passive chambers **51** and **51'** will increase. Control means **65** will, responsive to signals from pressure transducers **57** and **60**, cause pump **61** to supply additional hydraulic fluid to the active chambers to increase the downward force generated by the hydraulic fluid in such active chambers. The system is operated such that the upward force of the hydraulic fluid in the passive chambers, minus the downward force of the hydraulic fluid in the active chambers, continues to equal the selected upward force of 300,000 pounds necessary to maintain the BOP stationary.

As the floating vessel **13** moves downwardly in the water, the outer cylinders **43** and **43'** will move downwardly. The forces of gravity pulling downward on the blowout preventer will be opposed by the inertia of the blowout preventer, the water drag against the blowout preventer, and the upward forces of the fluid in the passive chambers against pistons **47** and **47'**. The upward force of the fluid in the passive chambers will be considerably in excess of the hook load and will move piston rods **41** and **41'** upwardly smoothly and affirmatively. As the piston rods move upwardly, the pressure of the hydraulic fluid in the passive chambers **52** and **52'** will decrease. Control means **65** will then cause pump **61** to withdraw additional hydraulic fluid from the active chambers **51** and **51'** to decrease the downward forces of the hydraulic fluid in the active chambers whereby the algebraic sum of the upward forces generated by the passive fluid and the downward forces generated by the active fluid continues to equal the 300,000 pound hook load.

The motion compensation and/or weight control system preferably is operated in the pressure mode when it is desired to maintain a selected weight on a tool in contact with the earth. Assume the system is being used with an earth-boring assembly mounted on a floating structure. Assume the hook **21** is supporting a total load of 350,000 comprising a drill string and drill bit. Assume that the toolpusher wishes to maintain the drill bit in contact with the earth at a pressure of 50,000 pounds. The hook load will then be 300,000 pounds.

The air in the bank **36** of air accumulator tanks is pressurized to the magnitude necessary to move piston rods **41** and **41'** to the top or near the top of their movement range with the entire 350,000 pound load supported by the hook. As previously explained, sufficient hydraulic fluid is supplied by pump **61** into the active chambers to lower the piston rods downward to the mid-point of their movement range. The control means **65** is then set whereby the system operates in the position mode and pump **61** introduces and withdraws hydraulic fluid into and out of the active chambers to maintain the drill string stationary relative to the earth. Cable **26** is then unwound from draw works **29** to the extent necessary to lower traveling block **27** and the expansible and contractible mechanism **22** sufficiently to place the drill bit in contact with the earth. The toolpusher will be aware that the earth has been contacted by the dead weight indicator **30** secured in cable **26** as illustrated in FIG. 1.

Potentiometers **102** and **112** are then adjusted to generate electrical signals proportional to the desired hook load, that is, 300,000 pounds, and the circuitry attendant to amplifier **111** is energized. The toolpusher

continues to unwind cable from the draw works. When the earth is supporting 50,000 pounds of the load and the expansible and contractible mechanism is supporting 300,000 pounds, the load being supported by mechanism **22** equals the selected hook load. At that point in time, amplifier **111** generates a logic signal which closes switch **103** and opens switch **90**. As the drill bit continues to move into the earth and the floating structure heaves, control means **65** operates in accordance with formula (2) above the cause pump **61** to introduce and withdraw hydraulic fluid to and from the active chambers so that the expansible and contractible mechanism **22** will maintain a constant 300,000 pound upward force on the load. Thus the system operates as an "automatic driller."

If the motion compensation and/or weight control system according to this invention is being used as an automatic driller in connection with a stationary earth-boring apparatus (such as a land rig), there is no need to move the piston rods **41** and **41'** downward a selected distance from the top of their movement range prior to commencing drilling. This downward movement of the piston rods is simply to give the expansible and contractible mechanism **22** room to contract in order to compensate for the possible downward movement of the floating structure. The rest of the procedure for operating the system would be as previously explained.

In addition, if drawworks **29** is equipped with a commercially available automatic driller, such as the automatic driller manufactured by Martin-Decker, which can unwind the cable **26** responsive to a selected signal, the improved motion compensation and/or weight control system according to this invention can accomplish another desirable function. When the system is being operated in the pressure mode as an "automatic driller," position transducers or limit switches (not shown) attached to the expansible and contractible mechanism can be utilized to determine when piston rods **41** and **41'** have moved downwardly a selected distance. Upon this occurrence, a selected signal can be transmitted to drawworks **29** to cause it to unwind a selected amount of cable **26**. Unwinding the cable causes the traveling block **27** to be moved downwardly a selected distance. This downward movement of the traveling block ordinarily would increase the hook load. However, as the traveling block moves downwardly and the hook load tends to increase, control means **65** will sense the increase in the pressure of the hydraulic fluid in the passive chambers and transmit the necessary signal to pump **61** to cause it to withdraw fluid from the active chambers. Piston rods **41** and **41'** will then move upwardly to maintain the selected 300,000 pound hook load.

5. Certain additional advantages

By increasing the pressure of the air in the passive portion of the system to a magnitude sufficient to move the piston rods to the top of their movement range and then utilizing the active portion of the system to bias the piston rods back down to the midpoint of their movement range, the improved motion compensation and/or weight control system of this invention is capable of obtaining maximum accuracy in supporting its load at all points within the telescoping movement range of its expansible and contractible mechanism, but with a minimum of horse-power.

The motion compensation and/or weight control system according to this invention can, due to the interaction of the passive and active portions of the system, provide rapid, smooth, and positive telescoping of its expansible and contractible mechanism, even with heavy hook loads. This is because, on the one hand, the passive portion of the system, unlike purely passive systems, is pressurized to a magnitude sufficient to move the load upward to the furthest limit of the movement range of the expansible and contractible mechanism. This is also because, on the other hand, only relatively small volumes of hydraulic fluid, compared with purely active systems, need be supplied to or withdrawn from the system to bias the expansible and contractible mechanism to any point of its movement range.

The improved motion compensation and/or weight control system according to this invention has still other advantages over prior purely passive or active systems. For example, even with a given magnitude load, it is often necessary to lift the load a selected distance, such as lifting the drill string to set it on the slips. When a purely passive motion compensation and/or weight control system is utilized to so lift the drill string, the pressure of the air in the bank of accumulator tanks must be increased to raise the piston rod above its normal operating position. As there is a large volume of air in the bank of accumulator tanks, considerable horsepower may be utilized. Once the drill bit is to again contact the earth, air must be bled out of the bank of accumulator tanks. In the motion compensation and/or weight control system according to this invention, the air in the bank of accumulator tanks is pressurized only once for any given load—to a magnitude sufficient to move the piston rods to the top of their stroke. Thereafter, downward movement of the piston rod is accomplished by providing hydraulic fluid to the active chambers. There is much less horse-power utilized in moving a relatively small volume of a non-compressible hydraulic fluid into and out of the active chambers than in repeatedly pressurizing and depressurizing a relatively large volume of a compressible gas.

The embodiment of the expansible and contractible mechanism 22 illustrated in FIGS. 1 and 2 is additionally advantageous in that the active chambers function as deceleration means. If the load should suddenly part and piston rods 41 and 41' move upwardly rapidly, the upward movement of pistons 47 and 47' will tend to force the hydraulic fluid in the active chambers back through conduit 59 and pump 61 into sump 63. The orifices 58 and 58' will restrict this flow and cause the hydraulic fluid in the active chambers to resist the upward movement of the piston rods. Of course the pressure of the hydraulic fluid in the active chambers will increase dramatically. If the inner cylinder 46 was not contained within the piston rod 41, the size of the inner cylinder would have to be substantially larger to withstand these great pressures. But in the embodiment of the invention disclosed in FIGS. 1 and 2, as the piston rods 41 and 41' move rapidly upward and cause the pressure of the active hydraulic fluid to increase, the piston rods themselves provide the necessary external support for the inner cylinders 46 and 46' to withstand this increased pressure.

In the embodiment of the motion compensation and/or weight control system illustrated in FIGS. 1 and 2, the load is attached to hook 21 at an elevation below

that at which support member 42 attaches to piston rods 41 and 41'. This produces a stability not found in certain prior art systems in which the piston rods straddle and extend below the hook and the load is attached to the hook at an elevation above that at which the support member attaches to the piston rod.

In the embodiment of the motion compensation and/or weight control system illustrated in FIGS. 1 and 2, the system, when operated in the position mode, provides compensation for a certain degree of lateral movement of the floating structure. If the floating structure should move laterally from above the well-head, additional cable 79 will be unwound from drum 38. Control means 65, operating responsive to signals received from the position and velocity transducers 80 and 81 associated with drum 38, will then cause pump 61 to supply additional hydraulic fluid to the active chambers to compensate for this lateral movement.

B. Alternative means for actively supplying and withdrawing hydraulic fluid to and from active portion of system

FIG. 5 illustrates an alternate means 37 for actively supplying and withdrawing hydraulic fluid into and from the active chambers 52 and 52'. An auxiliary compensating cylinder 116 is secured by vertical members 117 to the floating structure 13. Movable longitudinally within compensating cylinder 116 is a compensating piston 118. Piston 118 is slidably sealed against the interior of cylinder 116 by seal ring 119. Depending from the compensating piston 118 is a piston rod 120. Piston rod 120 extends through the lower end of compensating cylinder 116 and is slidably sealed thereagainst by seal ring 121. Secured to the lower end of piston rod 120 is a cable 122 which is secured to the sea bottom directly or otherwise.

The variable chamber 123 formed beneath piston 120 and within compensating cylinder 116 is the auxiliary compensating chamber 123. A port 124 is provided in the lower portion of compensating cylinder 116. Conduit 59 from the active chambers 52 and 52' (FIG. 2) provides fluid communication between the compensating chamber 123 and the active chambers 52 and 52'.

In operation, hydraulic fluid at a selected pressure is introduced into the closed system comprising the active chambers 52 and 52', conduit 59, and compensating chamber 123, by means (not shown) well known to those skilled in the art. The pressure of such active hydraulic fluid and the effective cross-sectional area of compensating chamber 123 are chosen such that the downward force of the hydraulic fluid in active chambers 52 and 52' against active pistons 50 and 50' will substantially compensate for the errors in the passive portion of the system. As the floating structure 13 moves vertically, compensating piston 118 will move vertically. The increasing and decreasing volume of compensating chamber 123 allows the active hydraulic fluid to flow through conduit 59 between the active chambers 52 and 52' and the compensating chamber 123.

For example, assume that the motion compensation and/or weight control system is supporting a 300,000 pound hook load. Assume that the air in bank 36 of air accumulator tanks (FIG. 2) has been pressurized to approximately 330,000 pounds. Assume that the cross-sectional area of compensating chamber 123 and the pressure of the hydraulic fluid therein is such that, with

compensating piston 118 in the mid-point of its movement range, the downward force produced by the hydraulic fluid in active chambers 52 and 52' against active pistons 50 and 50' is approximately 30,000 pounds. Assume that the piston rod 41 and 41' are stabilized in the mid-point of their movement range and the 300,000 pound hook load is being supported at equilibrium.

If floating structure 13 now moves upwardly, piston rods 47 and 47' will move downwardly with the load. Hydraulic fluid will be forced out of the passive chambers 51 and 51' into the oil/air interface tank 35, thereby compressing the air in the oil/air interface tank and the bank 36 of air accumulator tanks. As the air is compressed, its pressure will increase. Thus, piston rods 41 and 41' will not move downward as far as they should to compensate for the upward movement of the floating structure 13. However, as floating structure 13 moves upward, compensating piston 118 is pulled downward in compensating cylinder 116. This decreases the volume of compensating chamber 23 and forces hydraulic fluid from compensating chamber 123 through conduit 59 into the active chambers 52 and 52'. The pressure of the hydraulic fluid contained in compensating chamber 123 and the cross-sectional area of compensating chamber 123 has been chosen such that the increased force against active pistons 50 and 50' in active chambers 52 and 52' substantially equals and cancels the increase in the pressure of the hydraulic fluid in the passive chambers 51 and 51'. Thus, the piston rods 41 and 41' are moved downwardly to their proper position to compensate for the upward movement of floating structure 13.

When floating structure 13 moves downwardly, the undesirable drop in the pressure of the hydraulic fluid in the passive chambers 51 and 51' due to the expansion of the air in the oil/air interface tank and the bank of air accumulator tanks is compensated for by compensating piston 118 moving upwardly and allowing hydraulic fluid to flow from the active chambers 52 and 52' back to compensating chamber 123.

C. Alternative expansible and contractible mechanism

FIG. 6 illustrates an alternate embodiment of the expansible and contractible mechanism 22 of the improved motion compensation and/or weight control system according to this invention wherein the expansible and contractible mechanism 22 is designed to be releasably secured between the traveling block and the load. This embodiment of the expansible and contractible mechanism is constructed identical to the expansible and contractible mechanism described in FIG. 2, but preferably comprises a single piston and cylinder assembly, rather than two identical piston and cylinder assemblies. Preferably, outer cylinder 43 has an eyelet 127 secured thereto for engagement with a hook 128 depending from the traveling block 27. The single piston and cylinder assembly is constructed identical to the piston and cylinder assembly 39 described in FIG. 2. Preferably hook 21 is secured to piston 50 at the lower end of piston rod 41. Hook 21 engages with an eyelet 129 secured to the top of swivel 20.

The operation of the motion compensation and/or weight control system with such expansible and contractible mechanism 22 is as previously explained with respect to the system illustrated in FIGS. 1 through 5. Either the control means 65 and related equipment il-

lustrated in FIG. 2 or the means 37 illustrated in FIG. 5 may be utilized to move hydraulic fluid into and out of the active chamber 52.

When an earth-boring assembly is being utilized to "trip" drill string into and out of the hole, expansible and contractible mechanism 22 illustrated in FIG. 6 may be disconnected from the traveling block 27 and stored inside the derrick or on the floating structure 13. This eliminates weight during the "tripping" cycle and thus reduces cable wear and pulley wear. When the earth-boring apparatus again requires the use of the motion compensation and/or weight control system, the expansible and contractible mechanism 22 can be reattached beneath the traveling block 27.

D. Motion compensation and/or weight control system utilized with an earth-boring assembly having a drillhead

FIG. 7 illustrates an alternate embodiment of the improved motion compensation and/or weight control system according to this invention wherein the system is adapted for use with an earth-boring assembly utilizing a drill head rather than cables and blocks. Secured to floating structure 13 are vertical members 131 which support a horizontal support member 132. Secured to horizontal support member 132 is an expansible and contractible mechanism 22 according to this invention such as is illustrated and described in FIG. 2. Depending from the two piston rods 41 and 41' is a drill head assembly 133 such as is well known to those skilled in the art. Depending from the drill head assembly 133 is a drill string 14.

The operation of the system is as previously explained with respect to FIGS. 1 through 5. Hydraulic fluid preferably is supplied to and withdrawn from the active chambers 52 of the expansible and contractible mechanism 22 by the control means 65 and related equipment illustrated in FIG. 2 or the means 37 illustrated in FIG. 5.

E. Alternative expansible and contractible mechanism

FIG. 8 illustrates an alternate embodiment of the expansible and contractible mechanism 22 of the improved motion compensation and/or weight control system according to this invention. Secured between a first support member 134 and a second support member 135 are two passive piston and cylinder assemblies 136 and 136' and two active piston and cylinder assemblies 137 and 137'. The piston and cylinder assemblies could of course extend upward on either side of the traveling block 27. As previously explained, the forces produced by the active piston and cylinder assemblies 137 and 137' oppose the forces produced by the passive piston and cylinder assemblies 136 and 136'. The operation of the motion compensation and/or weight control system with the expansible and contractible mechanism 22 illustrated in FIG. 8 is as previously described with respect to FIGS. 1 through 5. Hydraulic fluid preferably is supplied to and withdrawn from each of the active piston and cylinder assemblies either by the control means 65 and related equipment illustrated in FIG. 2 or the means 37 illustrated in FIG. 5.

F. Alternative expansible and contractible mechanism

FIG. 9 illustrates still another embodiment of an expansible and contractible mechanism 22 of the improved motion compensation and/or weight control system according to this invention. Secured to traveling

block 27 is a support member 40. Secured to support member 40 on either side of traveling block 27 is a cylinder 138 and 138'. Movable longitudinally within each cylinder 138 and 138' is a piston 139. Extending upwardly from each of the pistons 139 is a relatively large piston rod 140 and 140'. Pivotaly attached to the top of each of the piston rods 140 and 140' is a pulley 141 and 141'. A cable 142 and 142' is reeved around pulleys 141 and 141' and extended downwardly through an opening (not shown) in support member 40. Cables 142 and 142' are secured to a support member 143 from which depends hook 21.

The variable chambers 144 beneath the pistons 139 are the passive chambers. The annular chambers 145 formed between piston rods 140 and 140' and cylinders 138 and 138' are the active chambers. Piston rods 140 and 140' are preferably formed to have a large cross-sectional area such that the cross-sectional area of the annular active chambers 145 are one-fourth or less the cross-sectional area of the passive chambers 144. Hydraulic fluid is supplied and withdrawn from the passive chambers through conduit 146. Hydraulic fluid is supplied to and withdrawn from the active chambers through conduit 147. The means for supplying hydraulic fluid to the passive chambers preferably is as illustrated in FIG. 2. The means for providing hydraulic fluid to the active chambers preferably is as illustrated in FIG. 2 or as illustrated in FIG. 5.

The operation of the motion compensation and weight control system utilizing the expansible and contractible mechanism 22 illustrated in FIG. 9 is as previously described: the forces of the hydraulic fluid in the active chambers 145 against pistons 139 oppose the forces of the hydraulic fluid in the passive chambers 144 against pistons 139. However, rather than the algebraic sum of the forces being supplied in a direct mechanical relationship to hook 21, such forces are doubled by being supplied through the piston rods 140 and 140' carrying pulleys 141 and 141' and cables 142 and 142'. This allows the stroke of the piston rods 140 and 140' to be halved.

G. Alternative embodiment of motion compensation and/or weight control system

FIG. 10 illustrates still another embodiment of the improved motion compensation and/or weight control system according to this invention. The manner of employing the expansible and contractible mechanism 22 within a derrick or otherwise is not shown. Extending longitudinally within and depending from outer cylinder 43 is an inner cylinder 46. Movable longitudinally within the annular chamber between the inner cylinder 46' and the outer cylinder 43 is a first piston 47. Attached to the first piston 47 is a piston rod 41 which slides along the outside of inner cylinder 46. Secured to the lower end of piston rod 41 is second piston 50. Inner cylinder 46, first piston 47, piston rod 41, and outer cylinder 43 are all secured in a slidably, sealing relationship whereby a primary chamber 51 and a secondary chamber 52 are formed similarly as described with respect to FIG. 2. Hydraulic fluid is passively supplied to primary chamber 51 through conduit 55 from an oil/air interface tank 35 and a bank 36 of air accumulator tanks as described with respect to FIG. 2.

However, unlike the previous embodiments of the improved motion compensation and weight control system according to this invention, a second port 150 is provided near the bottom of primary chamber 51. A

conduit 151 connects between this second port 150 and a port 152 at the top of secondary chamber 52. Thus, secondary chamber 51 is in fluid communication with primary chamber 52.

The principal of operation of this alternate embodiment of the invention is as previously described: the force of the hydraulic fluid in the primary chamber 51 against piston 47 is opposed by the force of the hydraulic fluid in the secondary chamber 52 against piston 50. However, in this embodiment the same hydraulic fluid is supplied to both the primary and secondary chambers.

In operation, assume that piston rod 41 is supporting a 300,000 pound load. The air in accumulator bank 36 is pressurized to a magnitude sufficient to support such load and move piston rod 41 to the approximate midpoint of its movement range. The pressure of the hydraulic fluid will be the same in the primary chamber 51 and the secondary chamber 52. Assuming that the ratio of the cross-sectional area of the primary chamber to the secondary chamber is precisely 4:1, the upward force of the hydraulic fluid against piston 47 may be 400,000 pounds and the downward force of the hydraulic fluid against piston 50 may be 100,000 pounds.

Now assume that the floating structure with which the system is associated moves upwardly. Piston rod 41 will move downwardly with respect to cylinder 43. As piston rod 41 moves downwardly, three-fourths of the hydraulic fluid displaced from primary chamber 51 is forced into oil/air interface tank 35 and one-fourth of the hydraulic fluid displaced from primary chamber 51 is forced into secondary chamber 52. Movement of three-fourths of the hydraulic fluid into the oil/air interface tank 35 compresses the volume of the air therein and in bank 36 of the air accumulator tanks and causes the pressure of such air to increase. Increasing the pressure of the air in the air accumulator tanks increases the pressure of the hydraulic fluid in both the primary chamber 51 and the secondary chamber 52. Increasing the pressure of the hydraulic fluid in the primary chamber 51 will, as previously described, cause an error in the compensation. However, the opposing downward force of the hydraulic fluid in the secondary chamber 52 is also increased somewhat due to the increase of the pressure of the hydraulic fluid contained therein. This increase in the opposing force produced by the hydraulic fluid in the secondary chamber 52 decreases the total error in the compensation or weight control.

Thus, the embodiment of the invention illustrated in FIG. 10 is a modified passive system wherein the compensation losses inherent in the prior art purely passive systems are decreased.

From the foregoing, it will be understood that this present invention provides an improved method and apparatus for motion compensation and/or weight control. It will now be apparent to those skilled in the art that the foregoing disclosure and description of the invention is illustrative and explanatory thereof, and various changes may be made in the construction of the improved method and apparatus within the scope of the appended claims without departing from the spirit of the invention.

What is claimed is:

1. in a load-supporting assembly for supporting a load which is movable relative to the load-supporting assembly, an improved motion compensation and/or weight control system, comprising:

an outer cylinder having end plates at either end thereof;

an inner cylinder disposed concentrically within the outer cylinder and depending from the first end plate;

a cylindrical piston rod slidably disposed around the inner cylinder and extending through the second end plate of the outer cylinder for longitudinal movement relative thereto;

one of the outer cylinder or the piston rod being mounted for movement with the load-supporting assembly and the other of the outer cylinder or the piston rod being mounted for movement with the load;

a first piston secured to the piston rod within the annular chamber between the inner cylinder and the outer cylinder and slidably sealed against the outer cylinder;

means for slidably sealing the piston rod against the inner cylinder;

means for slidably sealing the piston rod against the second end plate of the outer cylinder;

a second piston secured to and sealing the end of the piston rod opposite the end of the piston rod to which the first piston is secured;

the variable volume annular chamber formed between the piston rod, the first piston, the outer cylinder, and the second end plate of the outer cylinder, being the primary chamber;

the variable volume chamber formed within the first end plate of the outer cylinder, the inner cylinder, the piston rod, and the second piston, being the secondary chamber;

means in fluid communication with the primary chamber for passively supplying fluid under pressure to the primary chamber whereby force is supplied against the first piston tending to move the piston rod in the direction to support the load; and

means in fluid communication with the secondary chamber for actively supplying fluid into and allowing the withdrawal of fluid out of the secondary chamber whereby a biasing force may be supplied against the second piston tending to move the piston rod in the direction opposing the support of the load.

2. In a load-supporting assembly for supporting a load which is movable relative to the load-supporting assembly, an improved motion compensation and/or weight control system according to claim 1 wherein the means for passively supplying fluid under pressure to the primary chamber includes:

a pneumatic accumulator; and

a pneumatic-hydraulic interface means in fluid communication with the pneumatic-accumulator interface means and the primary chamber.

3. In a load supporting assembly for supporting a load which is movable relative to the load-supporting assembly, an improved motion compensation and/or weight control system according to claim 1, wherein the means for actively supplying fluid into and allowing the withdrawal of fluid out of the secondary chamber includes:

a source of hydraulic fluid;

a variable volume, bi-directional pump in fluid communication with the source of hydraulic fluid and in fluid communication with the active chamber; and

a control means for controlling the direction and the volume of the hydraulic fluid pumped by such pump.

4. In a load-supporting assembly for supporting a load which is movable relative to the load-supporting assembly, an improved motion compensation and/or weight control system according to claim 1 wherein the means for actively supplying fluid into and allowing the withdrawal of fluid out of the secondary chamber includes:

a piston and cylinder assembly forming a variable volume compensating chamber; and

a conduit connecting the compensating chamber and the secondary chamber;

the compensating chamber, the secondary chamber, and the interconnecting conduit being filled with hydraulic fluid.

5. In a load-supporting assembly for supporting a load which is movable relative to the load-supporting assembly, an improved motion compensation and/or weight control system, comprising:

an outer cylinder having end plates at either end thereof;

an inner cylinder disposed concentrically within the outer cylinder and depending from the first end plate;

a cylindrical piston rod slidably disposed around the inner cylinder and extending through the second end plate of the outer cylinder for longitudinal movement relative thereto;

one of the outer cylinder or the piston rod being mounted for movement with the load-supporting assembly and the other of the outer cylinder or the piston rod being mounted for movement with the load;

a first piston secured to the piston rod within the annular chamber between the inner cylinder and the outer cylinder and slidably sealed against the outer cylinder;

means for slidably sealing the piston rod against the inner cylinder;

means for slidably sealing the piston rod against the second end plate of the outer cylinder;

a second piston secured to and sealing the end of the piston rod opposite the end of the piston rod to which the first piston is secured;

the variable volume annular chamber formed between the piston rod, the first piston, the outer cylinder, and the second end plate of the outer cylinder, being the primary chamber;

the variable volume chamber formed within the first end plate of the outer cylinder, the inner cylinder, the piston rod, and the second piston, being the secondary chamber;

means for passively supplying fluid under pressure to the primary chamber; and

means for providing fluid communication between the primary chamber and the secondary chamber.

6. In a load-supporting assembly for supporting a load which is movable relative to the load-supporting assembly, an improved motion compensation and/or weight control system, comprising:

an outer cylinder having end plates at either end thereof;

an inner cylinder disposed concentrically within the outer cylinder and depending from the first end plate;

a cylindrical piston rod slidably disposed around the inner cylinder and extending through the second end plate of the outer cylinder for longitudinal movement relative thereto;

one of the outer cylinder or the piston rod being 5
mounted for movement with the load-supporting assembly and the other of the outer cylinder or the piston rod being mounted for movement with the load;

a first piston secured to the piston rod within the annular chamber between the inner cylinder and the outer cylinder and slidably sealed against the outer cylinder;

means for slidably sealing the piston rod against the inner cylinder;

means for slidably sealing the piston rod against the second end plate of the outer cylinder;

a second piston secured to and sealing the end of the piston rod opposite the end of the piston rod to which the first piston is secured;

the variable volume annular chamber formed between the piston rod, the first piston, the outer cylinder, and the second end plate of the outer cylinder, being the primary chamber,

the variable volume chamber formed within the first end plate of the outer cylinder, the inner cylinder, the piston rod, and the second piston, being the secondary chamber;

means in fluid communication with the primary chamber for passively supplying fluid under pressure to the primary chamber whereby force is supplied against the first piston tending to move the piston rod in the direction to support the load;

a first pressure transducer for sensing the pressure of the fluid in the primary chamber and for generating a first electrical signal proportional thereto;

means in fluid communication with the secondary chamber for actively supplying fluid under pressure into and allowing the withdrawal of such fluid from the secondary chamber whereby a biasing force may be supplied against the second piston tending to move the piston rod in the direction opposing the support of the load;

a second pressure transducer for sensing the pressure of the fluid in the secondary chamber and for generating a second electrical signal proportional thereto; and

control means operable responsive to the first and second electrical signals for controlling the means which actively supplies the fluid into and allows the withdrawal of the fluid from the secondary chamber.

7. In a load-supporting assembly for supporting a load which is movable relative to the load-supporting assembly, an improved motion compensation and/or weight control system according to claim 6, including: adjustable means for generating a third electrical signal proportional to a selected hook load carried by the system; and

wherein the control means are operable responsive to the first, second and third electrical signals to cause the fluid to be actively supplied into and withdrawn from the secondary chamber.

8. In a load-supporting assembly for supporting a load which is movable relative to the load-supporting assembly, an improved motion compensation and/or weight control system, comprising:

an outer cylinder having end plates at either end thereof;

an inner cylinder disposed concentrically within the outer cylinder and depending from the first end plate;

a cylindrical piston rod slidably disposed around the inner cylinder and extending through the second end plate of the outer cylinder for longitudinal movement relative thereto;

one of the outer cylinder or the piston rod being mounted for movement with the load-supporting assembly and the other of the outer cylinder or the piston rod being mounted for movement with the load;

a first piston secured to the piston rod within the annular chamber between the inner cylinder and the outer cylinder and slidably sealed against the outer cylinder;

means for slidably sealing the piston rod against the inner cylinder;

means for slidably sealing the piston rod against the second end plate of the outer cylinder;

a second piston secured to and sealing the end of the piston rod opposite the end of the piston rod to which the first piston is secured;

the variable volume annular chamber formed between the piston rod, the first piston, the outer cylinder, and the second end plate of the outer cylinder, being the primary chamber;

the variable volume chamber formed within the first end plate of the outer cylinder, the inner cylinder, the piston rod, and the second piston, being the secondary chamber;

means for determining the direction and velocity of the movement of the piston rod relative to the outer cylinder and for generating an electrical signal proportional thereto;

means in fluid communication with the primary chamber for passively supplying fluid under pressure to the primary chamber whereby force is supplied against the first piston tending to move the piston rod in the direction to support the load;

means in fluid communication with the primary chamber for actively supplying fluid into and allowing the withdrawal of fluid from the secondary chamber whereby a biasing force may be applied against the second piston tending to move the piston rod in the direction opposing the support of the load; and

control means operable responsive to the electrical signal for controlling the means which actively supplies fluid into and allows the withdrawal of fluid out of the secondary chamber.

9. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system, comprising:

a primary piston and cylinder assembly interposed between the traveling block and the load, one of the primary piston and the primary cylinder being mounted for movement with the traveling block and the other of a primary piston and the primary cylinder being mounted for movement with the load;

a secondary piston and cylinder assembly interposed between the traveling block and the load, the sec-

ondary cylinder being disposed concentrically within the primary cylinder, one of the secondary piston and the secondary cylinder being mounted for movement with the traveling block and the other of the secondary piston and the secondary cylinder being mounted for movement with the load;

a cylindrical piston rod slidably disposed around the secondary cylinder and extending beyond the primary cylinder for longitudinal movement relative to the primary and secondary cylinders;

the primary piston being secured to the end of the piston rod within the annular chamber between the primary cylinder and the secondary cylinder and slidably sealed against the primary cylinder;

the secondary piston being secured to and sealing the end of the piston rod opposite the end of the piston rod to which the primary piston is secured;

means for passively maintaining fluid under pressure in the primary cylinder and on a selected side of the primary piston whereby force is provided against the primary piston tending to move the primary piston longitudinally relative to the primary and secondary cylinders in the direction to support the load; and

means for actively supplying fluid into the secondary cylinder and onto a selected side of the secondary piston and allowing the withdrawal of fluid from the secondary cylinder whereby force is provided against the secondary piston for moving the secondary piston longitudinally relative to the primary and secondary cylinders in the direction to oppose the supporting of the load.

10. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system according to claim 9, wherein the means for passively maintaining fluid under pressure in the primary cylinder and on a selected side of the primary piston includes:

a pneumatic accumulator;

a pneumatic-hydraulic interface means in fluid communication with the pneumatic accumulator; and

means for providing fluid communication between the pneumatic-hydraulic interface means and the primary cylinder.

11. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system according to claim 9, wherein the means for actively introducing fluid into the secondary cylinder and allowing the withdrawal of fluid from the secondary cylinder includes:

a source of hydraulic fluid;

a variable volume, bi-directional pump in fluid communication with the active cylinder; and

control means coupled to the pump for controlling the direction and the volume of the hydraulic fluid pumped by such pump.

12. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system according to claim 9 wherein the means for actively introducing fluid under pressure into

the secondary cylinder and allowing the withdrawal of fluid from the secondary cylinder includes:

an auxiliary piston and cylinder assembly forming an auxiliary variable volume chamber, one of the auxiliary piston and the auxiliary cylinder being supported in a fixed position relative to the floating structure and the other of the auxiliary piston and the auxiliary cylinder being fixed relative to the earth; and

a conduit providing fluid communication between the auxiliary variable volume chamber and the secondary cylinder.

13. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system, comprising:

a primary piston and cylinder assembly interposed between the traveling block and the load, one of the primary piston and the primary cylinder being mounted for movement with the traveling block and the other of the primary piston and the primary cylinder being mounted for movement with the load;

means for passively maintaining fluid under pressure in the primary cylinder and on a selected side of the primary piston whereby force is provided against the primary piston for moving the primary piston longitudinally relative to the primary cylinder in the direction to support the load;

a secondary piston and cylinder assembly interposed between the traveling block and the load, one of the secondary piston and the secondary cylinder being mounted for movement with the traveling block and the other of the secondary piston and the secondary cylinder being mounted for movement with the load;

the primary and secondary pistons being operatively connected for coordinated movement;

means for actively introducing fluid into the secondary cylinder and onto a selected side of the secondary piston and allowing the withdrawal of the fluid from the secondary cylinder whereby force is provided against the secondary piston tending to move the secondary piston longitudinally relative to the secondary cylinder in the direction to oppose the supporting of the load;

transducer means for determining the pressure of the fluid in the primary cylinder and for generating a first electrical signal proportional thereto;

transducer means for determining the pressure of the fluid in the secondary cylinder and for generating a second electrical signal proportional thereto;

adjustable means for generating a third electrical signal proportional to a selected hook load; and

control means operable responsive to the first, second, and third electrical signals to cause the fluid to be actively supplied into and withdrawn from the secondary chamber.

14. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system according to claim 13, wherein the means for passively maintaining fluid under pressure in the primary cylinder and on a selected side of the primary piston includes:

a pneumatic accumulator;
 a pneumatic-hydraulic interface means in fluid communication with the pneumatic accumulator; and means for providing fluid communication between the pneumatic-hydraulic interface means and the primary cylinder.

15. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system according to claim 13, wherein the means for actively introducing fluid into the secondary cylinder and allowing the withdrawal of fluid from the secondary cylinder includes:

a source of hydraulic fluid;
 a variable volume, bi-directional pump in fluid communication with the active cylinder; and control means coupled to the pump for controlling the direction and the volume of the hydraulic fluid pumped by such pump.

16. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system according to claim 13 wherein the means for actively introducing fluid under pressure into the secondary cylinder and allowing the withdrawal of fluid from the secondary cylinder includes:

an auxiliary piston and cylinder assembly forming an auxiliary variable volume chamber, one of the auxiliary piston and the auxiliary cylinder being supported in a fixed position relative to the floating structure and the other of the auxiliary piston and the auxiliary cylinder being fixed relative to the earth; and
 a conduit providing fluid communication between the auxiliary variable volume chamber and the secondary cylinder.

17. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system, comprising:

a primary piston and cylinder assembly interposed between the traveling block and the load, one of the primary piston and the primary cylinder being mounted for movement with the traveling block and the other of the primary piston and the primary cylinder being mounted for movement with the load;

means for passively maintaining fluid under pressure in the primary cylinder on a selected side of the primary piston whereby force is exerted against the primary piston tending to move the primary piston longitudinally relative to the primary cylinder in the direction to support the load;

a secondary piston and cylinder assembly interposed between the traveling block and the load, one of the secondary piston and the secondary cylinder being mounted for movement with the traveling block and the other of the secondary piston and the secondary cylinder being mounted for movement with the load;

means for actively introducing fluid into the secondary cylinder on a selected side of the secondary piston and allowing the withdrawal of fluid from the secondary cylinder whereby force is exerted

against the secondary piston tending to move the secondary piston longitudinally relative to the secondary cylinder in the direction to oppose the supporting of the load;

means operatively connecting the primary and secondary pistons together whereby their longitudinal movement is coordinated together;

means associated with the floating structure for determining the direction and velocity of the vertical movement of the floating structure relative to the earth and for generating a first electrical signal proportional thereto;

means associated with the motion compensation system for determining the direction and the velocity of the vertical movement of the load relative to the traveling block and for generating a second electrical signal proportional thereto; and

control means operable responsive to the first and second electrical signals for causing the fluid to be actively introduced into the secondary cylinder and allowing the withdrawal of the fluid from the secondary cylinder.

18. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system according to claim 17, wherein the means for passively maintaining fluid under pressure in the primary cylinder and on a selected side of the primary piston includes:

a pneumatic accumulator;
 a pneumatic-hydraulic interface means in fluid communication with the pneumatic accumulator; and means for providing fluid communication between the pneumatic-hydraulic interface means and the primary cylinder.

19. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system according to claim 17, wherein the means for actively introducing fluid into the secondary cylinder and allowing the withdrawal of fluid from the secondary cylinder includes:

a source of hydraulic fluid;
 a variable volume, bi-directional pump in fluid communication with the active cylinder; and control means coupled to the pump for controlling the direction and the volume of the hydraulic fluid pumped by such pump.

20. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system according to claim 17, wherein the means for actively introducing fluid under pressure into the secondary cylinder and allowing the withdrawal of fluid from the secondary cylinder includes:

an auxiliary piston and cylinder assembly forming an auxiliary variable volume chamber, one of the auxiliary piston and the auxiliary cylinder being supported in a fixed position relative to the floating structure and the other of the auxiliary piston and the auxiliary cylinder being fixed relative to the earth; and

a conduit providing fluid communication between the auxiliary variable volume chamber and the secondary cylinder.

21. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system, comprising:

a cylinder having first and second end plates mounted for movement with the traveling block; a piston within the cylinder and slidably sealed there-against;

a piston rod attached to the piston and extending through and slidably sealed against the first end plate, the piston rod being mounted for movement with the load;

the variable chamber formed by the second end plate of the cylinder, the cylinder, and the piston, being the primary chamber;

the variable annular chamber between the first end plate of the cylinder, the cylinder, the piston rod, and the piston, being the secondary chamber;

means for passively maintaining fluid under pressure in the primary chamber whereby force is exerted against the piston tending to move the piston in the direction to support the load;

means for actively introducing fluid into the secondary chamber and allowing the withdrawal of fluid from the secondary chamber whereby force is exerted against the piston tending to move the piston in the direction opposing the support of the load;

transducer means for determining the pressure of the fluid in the secondary chamber and for generating a first electrical signal proportional thereto;

transducer means for determining the pressure of the fluid in the secondary chamber and for generating a second electrical signal proportional thereto;

adjustable means for generating a third electrical signal proportional to the selected hook load;

control means operable responsive to the first, second, and third electrical signals for causing the fluid to be actively introduced into the secondary chamber and allowing the withdrawal of the fluid from the secondary chamber.

22. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system according to claim 21, including: pulley means pivotally connected to the end of the piston rod which extends through the cylinder; and a cable connected to the cylinder, extending around the pulley, and connected to the load.

23. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system according to claim 21, wherein the means for passively maintaining fluid under pressure in the primary chamber includes:

a pneumatic accumulator;

a pneumatic-hydraulic interface means in fluid communication with the pneumatic accumulator; and

means for providing fluid communication between the pneumatic-hydraulic interface means and the primary chamber.

24. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system according to claim 21 wherein the means for actively introducing the fluid into the secondary chamber and allowing the withdrawal of the fluid from the secondary chamber includes:

a source of hydraulic fluid;

a variable volume, bi-directional pump in fluid communication with the source of hydraulic fluid and in fluid communication with the active chamber; and

control means coupled to the pump for controlling the direction and the volume of the hydraulic fluid pumped by such pump.

25. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system according to claim 21, wherein the means for actively introducing the fluid into the secondary chamber and allowing the withdrawal of the fluid from the secondary chamber includes:

an auxiliary piston and cylinder assembly forming an auxiliary variable volume chamber, one of the auxiliary piston and the auxiliary cylinder being supported in a fixed position relative to the floating structure and the other of the auxiliary piston and the auxiliary cylinder being fixed relative to the earth; and

a conduit providing fluid communication between the auxiliary variable volume chamber and the secondary chamber.

26. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system, comprising:

a cylinder having first and second end plates mounted for movement with the traveling block; a piston within the cylinder and slidably sealed there-against;

a piston rod attached to the piston and extending through and slidably sealed against the first end plate, the piston rod being mounted for movement with the load;

the variable chamber formed by the second end plate of the cylinder, the cylinder, and the piston, being the primary chamber;

the variable chamber between the first end plate of the cylinder, the cylinder, the piston rod, and the piston, being the secondary chamber;

means for passively maintaining fluid under pressure in the primary chamber whereby force is exerted against the piston tending to move the piston in the direction to support the load;

means for actively introducing fluid into the secondary chamber and allowing the withdrawal of fluid from the secondary chamber whereby force is exerted against the piston tending to move the piston in the direction opposing the supporting of the load;

means associated with the floating structure for determining the direction and the velocity of the vertical movement of the floating structure relative to

the earth and for generating a first electrical signal proportional thereto;
 means associated with the motion compensation system for determining the direction and the velocity of the vertical movement of the load relative to the traveling block and for generating a second electrical signal proportional thereto;
 control means operable responsive to the first and second electrical signals for causing the fluid to be introduced into the secondary chamber and allowing the withdrawal of the fluid from the secondary chamber.

27. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system according to claim 26, including:
 pulley means pivotally connected to the end of the piston rod which extends through the cylinder; and a cable connected to the cylinder, extending around the pulley, and connected to the load.

28. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system according to claim 26 wherein the means for passively maintaining fluid under pressure in the primary chamber includes:
 a pneumatic accumulator;
 a pneumatic-hydraulic interface means in fluid communication with the pneumatic accumulator; and means for providing fluid communication between the pneumatic-hydraulic interface means and the primary chamber.

29. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system according to claim 26, wherein the means for actively introducing the fluid into the secondary chamber and allowing the withdrawal of the fluid from the secondary chamber includes:
 a source of hydraulic fluid;
 a variable volume, bi-directional pump in fluid communication with the source of hydraulic fluid and in fluid communication with the active chamber; and
 control means coupled to the pump for controlling the direction and the volume of the hydraulic fluid pumped by such pump.

30. In an earth boring apparatus having a cable operated traveling block from which is hooked or suspended a load comprising a drill string or the like with a tool secured thereto, a motion compensation and/or weight control system according to claim 26, wherein the means for actively introducing the fluid into the secondary chamber and allowing the withdrawal of the fluid from the secondary chamber includes:
 an auxiliary piston and cylinder assembly forming an auxiliary variable volume chamber, one of the auxiliary piston and the auxiliary cylinder being supported in a fixed position relative to the floating structure and the other of the auxiliary piston and the auxiliary cylinder being fixed relative to the earth; and

a conduit providing fluid communication between the auxiliary variable volume chamber and the secondary chamber.

31. In an earth boring apparatus mounted on a floating structure and having a drill head or the like supporting a load, an improved motion compensation and/or weight control system comprising:
 a primary piston and cylinder assembly interposed between the floating structure and the drill head, one of the primary piston and the primary cylinder being mounted for movement with the floating structure and the other of the primary piston and the primary cylinder being mounted for movement with the drill head;
 means for passively maintaining fluid under pressure in the primary cylinder and on a selected side of the primary piston whereby force is exerted against the primary piston tending to move the primary piston longitudinally relative to the primary cylinder in the direction to support the load;
 a secondary piston and cylinder assembly interposed between the floating structure and the drill head, one of the secondary piston and the secondary cylinder being mounted for movement with the floating structure and the other of the secondary piston and the secondary cylinder being mounted for movement with the drill head;
 means for actively introducing fluid into the secondary cylinder and onto a selected side of the secondary piston and allowing the withdrawal of the fluid from the secondary cylinder whereby force is exerted against the secondary piston tending to move the secondary piston longitudinally relative to the secondary cylinder in the direction to oppose the supporting of the load;
 means for operatively connecting the primary and secondary pistons whereby their longitudinal movement is coordinated together;
 transducer means for determining the pressure of the fluid in the primary cylinder and for generating a first electrical signal proportional thereto;
 transducer means for determining the pressure of the fluid in the secondary cylinder and for generating a second electrical signal proportional thereto;
 adjustable means for generating a third electrical signal proportional to the selected hook load; and
 control means operable responsive to the first, second, and third electrical signals for causing the fluid to be introduced into the secondary cylinder and allowing the fluid to be withdrawn from the secondary chamber.

32. In an earth boring apparatus mounted on a floating structure and having a drill head or the like supporting a load, an improved motion compensation and/or weight control system comprising:
 a primary piston and cylinder assembly interposed between the floating structure and the drill head, one of the primary piston and the primary cylinder being mounted for movement with the floating structure and the other of the primary piston and the primary cylinder being mounted for movement with the drill head;
 means for passively maintaining fluid under pressure in the primary cylinder and on a selected side of the primary piston whereby force is exerted against the primary piston tending to move the primary piston

longitudinally relative to the primary cylinder in the direction to support the load;

a secondary piston and cylinder assembly interposed between the floating structure and the drill head, one of the secondary piston and the secondary cylinder being mounted for movement with the floating structure and the other of the secondary piston and the secondary cylinder being mounted for movement with the drill head;

means for actively introducing fluid into the secondary cylinder and onto a selected side of the secondary piston and allowing the withdrawal of the fluid from the secondary cylinder whereby force is exerted against the secondary piston tending to move the secondary piston longitudinally relative to the secondary cylinder in the direction to oppose the supporting of the load;

means for operatively connecting the primary and secondary pistons whereby their longitudinal movement is coordinated together;

means associated with the floating structure for determining the direction and the velocity of the vertical movement of the floating structure relative to the earth and for generating a first electrical signal proportional thereto;

means associated with the motion compensation system for determining the direction and the velocity of the vertical movement of the drill head relative to the floating structure and for generating a second electrical signal proportional thereto; and

control means operable responsive to the first and second electrical signals for causing the fluid to be actively introduced into the secondary cylinder and allowing the withdrawal of the fluid from the secondary cylinder.

33. In a load supporting assembly mounted on a floating structure for supporting a load movable vertically relative to the floating structure, a motion compensation and/or weight control system, including:

an expansible and contractible mechanism secured between the floating structure and the load;

means for determining the velocity of the vertical movement of the floating structure relative to the earth and generating a first electrical signal proportional thereto;

means for determining the velocity of the expansion and contraction of the expansible and contractible mechanism and generating a second electrical signal proportional thereto;

means for determining the vertical position of the floating structure relative to the earth and generating a third electrical signal proportional thereto;

means for determining the magnitude of expansion and contraction of the expansible and contractible mechanism and generating a fourth electrical signal proportional thereto;

means for actively supplying fluid to the expansible and contractible mechanism and allowing the withdrawal of the fluid from the expansible and contractible mechanism to cause it to expand and contract; and

control means operable responsive to the first, second, third and fourth electrical signals for controlling the operation of the means for actively supplying the fluid and allowing the withdrawal of the fluid, the control means including means operable responsive to the first, second, third and fourth

electrical signals for generating a fifth electrical signal proportional to Q in the following equation:

$$Q = k_1 (Vs) + k_2 (Ve) + k_3 (Le).$$

34. In a load supporting assembly mounted on a floating structure for supporting a load movable vertically relative to the floating structure, a motion compensation and/or weight control system according to claim 33, wherein the means for actively supplying fluid into the expansible and contractible mechanism and allowing the withdrawal of the fluid from the expansible and contractible mechanism includes:

a bi-directional, variable volume pump;

a source of hydraulic fluid;

means establishing fluid communication between the source of fluid and the pump and between the pump and the expansible and contractible mechanism; and

a servo valve coupled to the output of the control means and operable responsive to the fifth electrical signal for controlling the pump.

35. In a load-supporting assembly which is mounted on a floating structure, which load-supporting assembly supports a load movable vertically with respect to the floating structure and which load-supporting assembly includes a motion compensation and/or weight control system associated therewith, the system including a primary piston and cylinder assembly mounted between the load-supporting assembly and the load for generating forces tending to lift the load and a secondary piston and cylinder assembly mounted between the load-supporting assembly and the load for generating forces tending to oppose the lifting of the load and having the primary and secondary pistons operatively connected to each other for coordinated movement, the method of compensating for the movement of the floating structure, including the steps of:

passively supplying fluid under pressure into the primary cylinder and against the primary piston whereby each of the primary and secondary pistons is moved longitudinally within its cylinder a selected distance in the direction to lift the load and the system thereby lifts the load;

actively supplying hydraulic fluid into the secondary cylinder and against the secondary piston whereby each of the secondary and primary pistons is moved longitudinally within its cylinder a selected distance in the direction opposite to that for lifting the load and the system thereby lowers the load; and, thereafter,

actively supplying hydraulic fluid into and allowing the withdrawal of hydraulic fluid out of the secondary cylinder responsive to data indicative of the vertical movement of the floating structure relative to the earth, the magnitude of the expansion and contraction of the piston and cylinder assemblies, the velocity of the vertical movement of the floating structure relative to the earth, and the velocity of the expansion and contraction of the piston and cylinder assemblies, whereby the piston and cylinder assemblies expand and contract to compensate for the movement of the floating structure.

36. In a load-supporting assembly which is mounted on a floating structure, which load-supporting assembly supports a load movable vertically with respect to the floating structure and which load-supporting assembly includes a motion compensation and/or weight control

system associated therewith, the system including a primary piston and cylinder assembly mounted between the load-supporting assembly and the load for generating forces tending to lift the load and a secondary piston and cylinder assembly mounted between the load-supporting assembly and the load for generating forces tending to oppose the lifting of the load and having the primary and secondary pistons operatively connected to each other for coordinated movement, the method of compensating for the movement of the floating structure, including the steps of:

passively supplying fluid under pressure into the primary cylinder and against the primary piston whereby each of the primary and secondary pistons is moved longitudinally within its cylinder and a selected distance in the direction to lift the load and the system thereby lifts the load;

actively supplying hydraulic fluid into the secondary cylinder and against the secondary piston whereby each of the secondary and primary pistons is moved longitudinally within its cylinder a selected distance in the direction opposite to that for lifting the load and the system thereby lowers the load; and, thereafter,

actively supplying hydraulic fluid into and allowing the withdrawal of hydraulic fluid out of the secondary cylinder responsive to data indicative of the vertical movement of the floating structure relative to the earth, the magnitude of the expansion and contraction of the piston and cylinder assemblies, the velocity of the vertical movement of the floating structure relative to the earth, and the velocity of the expansion and contraction of the piston and cylinder assemblies, whereby the piston and cylinder assemblies expand and contract to compensate for the movement of the floating structure;

such step of actively supplying hydraulic fluid into and allowing the withdrawal of hydraulic fluid out of the secondary cylinder including solving the equation:

$$Q = k_1(Vs) + k_2(Ve) + k_3(Le).$$

37. In a load-supporting assembly which is mounted on a floating structure, which load-supporting assembly supports a load movable vertically with respect to the floating structure and which load-supporting assembly includes a motion compensation and/or weight control system associated therewith, the system including a primary piston and cylinder assembly mounted between the load-supporting assembly and the load for generating forces tending to lift the load and a secondary piston and cylinder assembly mounted between the load-supporting assembly and the load for generating forces tending to oppose the lifting of the load and having the primary and secondary pistons operatively connected to each other for coordinated movement, the method of compensating for the movement of the floating

structure and/or the movement of the load into the earth whereby a substantially constant pressure is maintained between the load and the earth, including the steps of:

passively supplying fluid under pressure into the primary cylinder and against the primary piston whereby each of the primary and secondary pistons is moved longitudinally within its cylinder a selected distance in the direction to lift the load and the system thereby lifts the load;

actively supplying hydraulic fluid into the secondary cylinder and against the secondary piston whereby each of the secondary and primary pistons is moved longitudinally within its cylinder a selected distance in the direction opposite to that for lifting the load and the system thereby lowers the load;

lowering at least the portion of the system comprising the primary and secondary piston and cylinder assemblies and the load mounted therefrom until the load is in contact with the earth and a selected pressure exists between the load and the earth; and, thereafter,

actively supplying hydraulic fluid into and allowing the withdrawal of hydraulic fluid out of the secondary cylinder responsive to data indicative of the pressure of the fluid in the primary cylinder and the pressure of the hydraulic fluid in the secondary cylinder, whereby the piston and cylinder assemblies expand and contract to compensate for the movement of the floating structure relative to the earth and/or the movement of the load into the earth.

38. In a load-supporting assembly which is mounted on a floating structure, which load-supporting assembly supports a load movable vertically with respect to the floating structure and which load-supporting assembly includes a motion compensation and/or weight control system associated therewith, the system including a primary piston and cylinder assembly mounted between the load-supporting assembly and the load for generating forces tending to lift the load and a secondary piston and cylinder assembly mounted between the load-supporting assembly and the load for generating forces tending to oppose the lifting of the load and having the primary and secondary pistons operatively connected to each other for coordinated movement, the method of compensating for the movement of the floating structure and/or the movement of the load into the earth whereby a substantially constant pressure is maintained between the load and the earth, according to claim 37, wherein the step of actively supplying hydraulic fluid into and allowing the withdrawal of hydraulic fluid out of the secondary cylinder includes the step of solving the following equation:

$$Q = (P_1 A_1 - P_2 A_2) - k$$

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