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Ahlstone et al.

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[54] COMPENSATING AND SENSING APPARATUS FOR WELL BORE DRILLING VESSELS

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[52] **U.S. Cl.** **166/.5**, 175/5, 175/27, 254/172

[51] **Int. Cl.** **E21b 19/08**

[58] **Field of Search** ....175/5, 27; 166/.5, .6; 254/172

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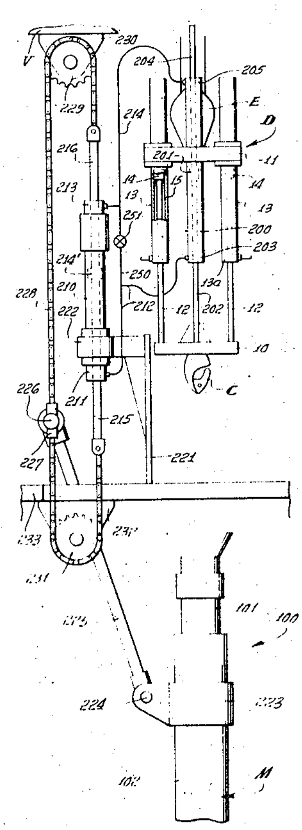
[57] **ABSTRACT**

Apparatus automatically compensating for relative vertical movement between a hoisting or supporting mechanism and a load carried thereby, which load, for example, may be a running string connected to a drill bit used in drilling a subaqueous well bore, the mechanism supporting the running string being mounted on a floating vessel anchored over the well bore. The compensating apparatus includes a cylinder and piston device containing a hydraulic fluid exerting a lifting or tensioning force on the running string, or other load, the pressure on the hydraulic fluid being maintained generally constant despite relative axial movement between the cylinder and piston portions of the device that might result from heaving of the vessel due to wind and wave action, or the lowering of the running or drilling string as the bit drills the hole. To insure that the apparatus will closely follow the movement of the floating vessel, a motion sensing system is employed that exerts a force to move the cylinder and piston of the compensating apparatus with respect to each other a distance equal to the vertical movement of the floating vessel.

19 Claims, 5 Drawing Figures



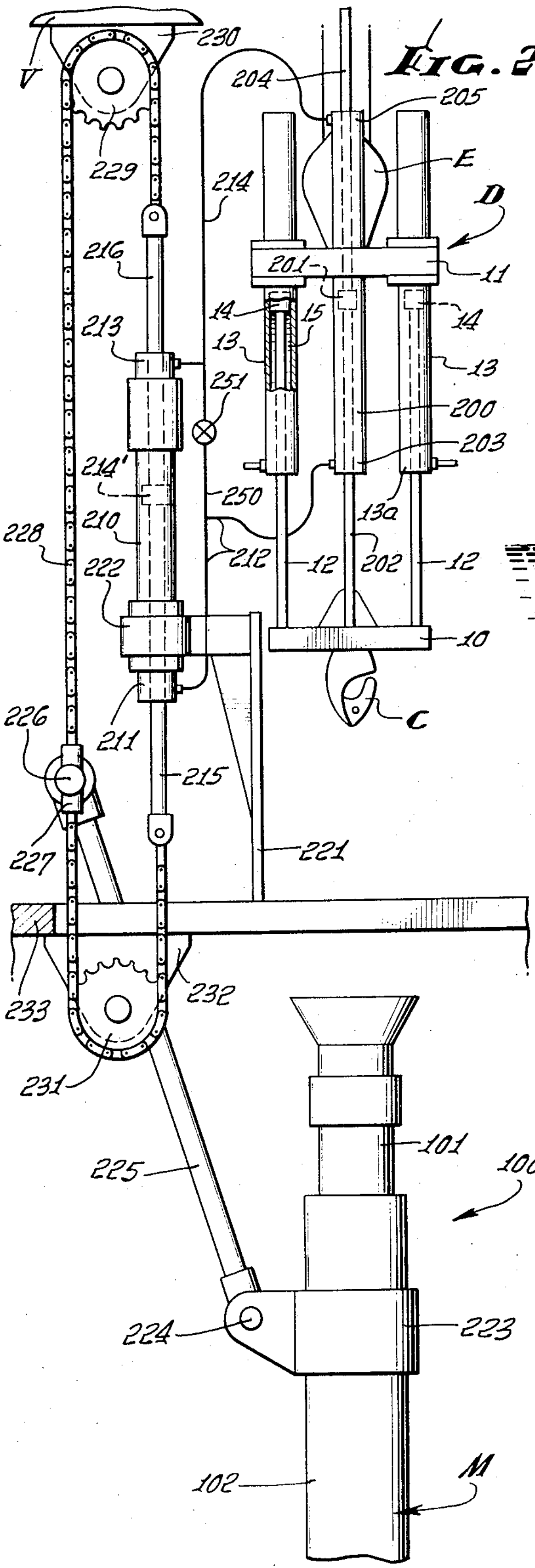


FIG. 2.

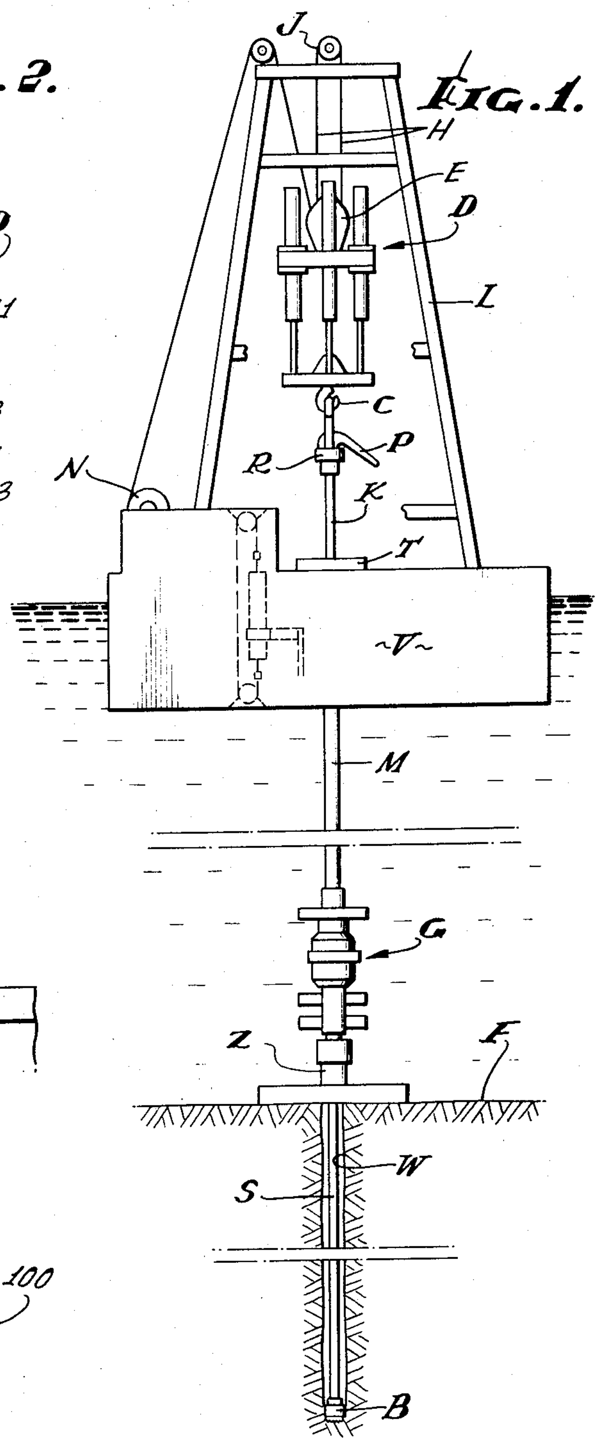


FIG. 1.

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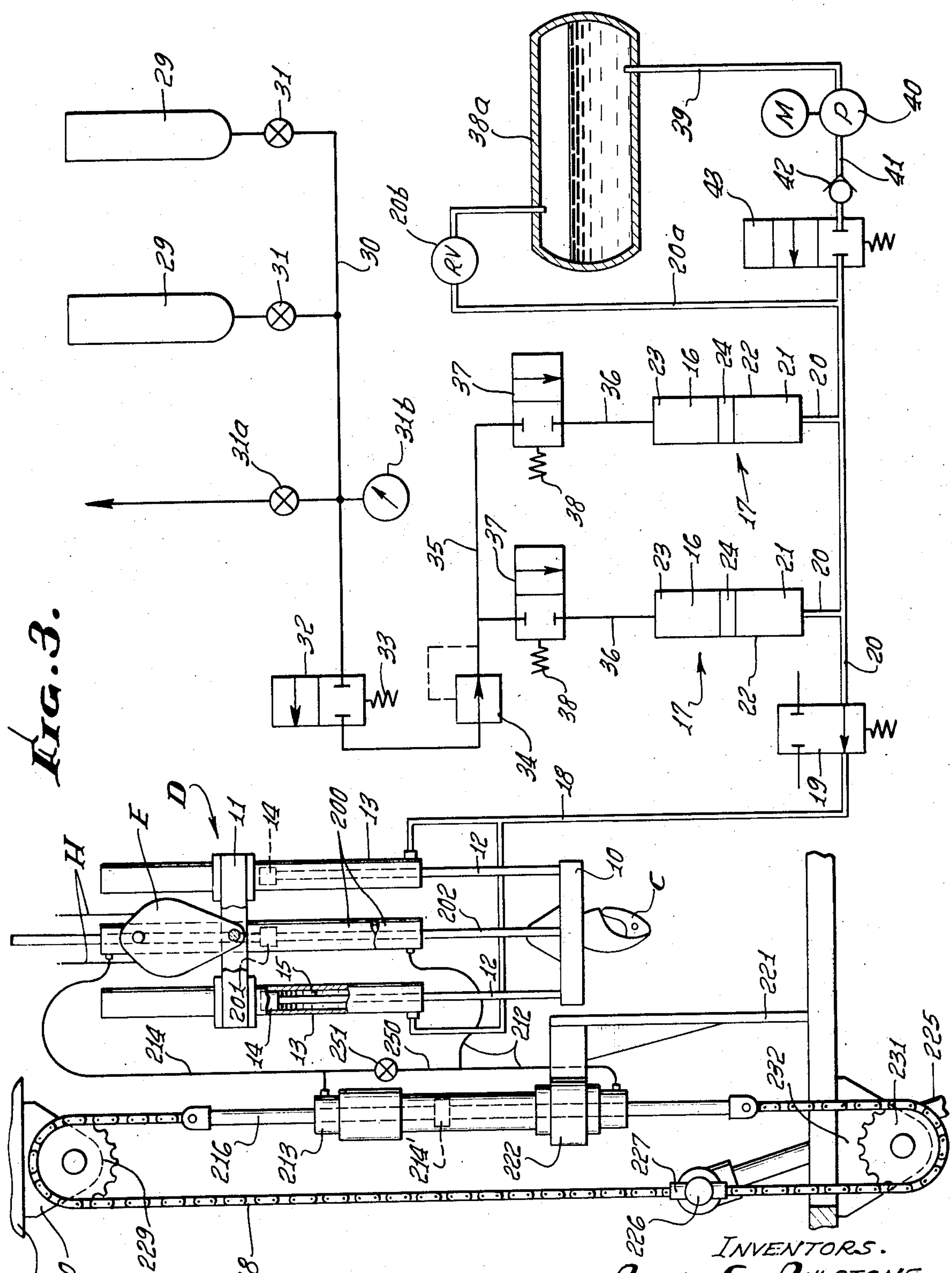

FIG. 3.

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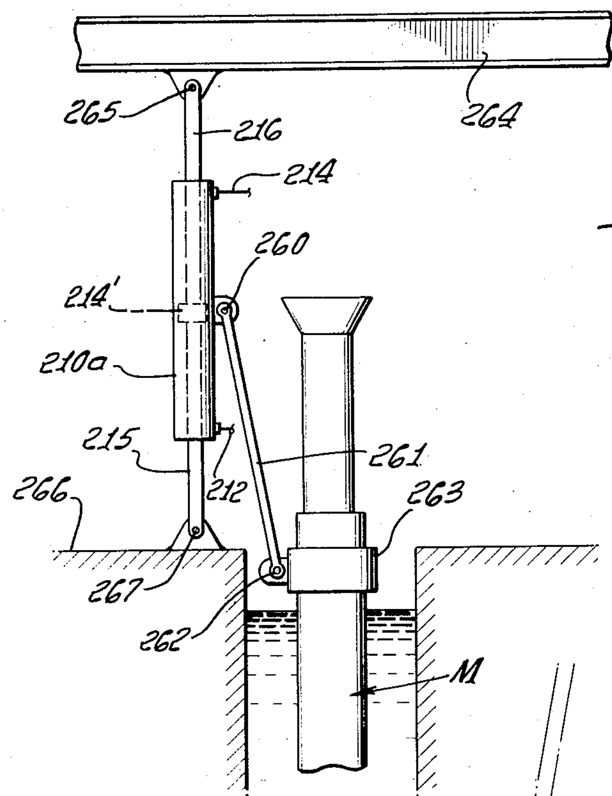

FIG. 4.

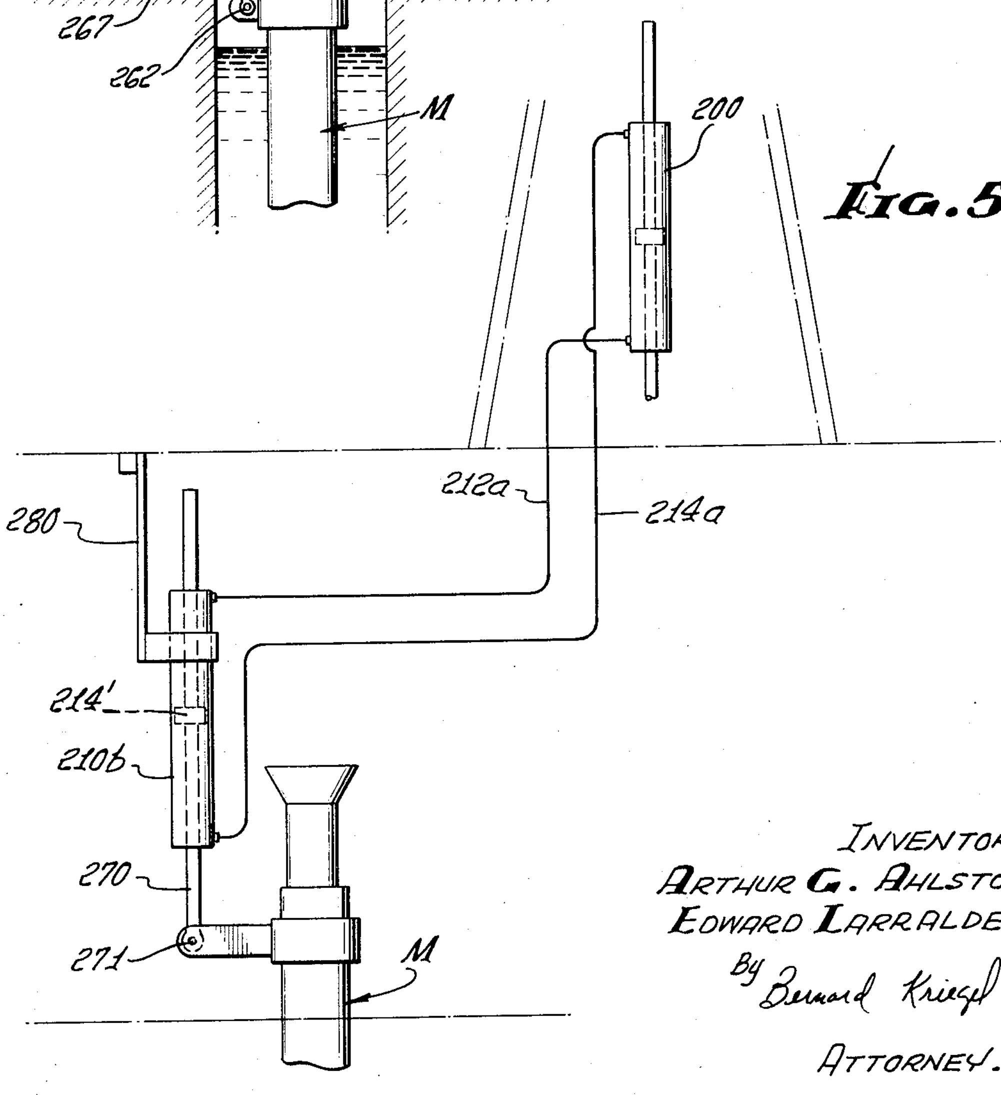

FIG. 5.

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COMPENSATING AND SENSING APPARATUS FOR WELL BORE DRILLING VESSELS

The present invention relates to apparatus for controlling the stress in a running string, and more particularly to apparatus used on or in connection with a floating vessel for maintaining the strain in a running string (such as a pipe string or cable) substantially constant while being used in the performance of diverse functions in a subaqueous well bore, such as drilling, fishing, completion, or other, operations therein, despite vertical movement of the vessel while such operations are being performed.

In the normal operation of drilling a well bore on land, or from a drilling platform supported in a fixed position from the ocean floor, the weight on the drill bit is equal to the total weight of the drilling string, less the weight of the drill pipe carried by the drawworks. Usually, the weight imposed on the bit is equal to the weight of the drill collar sections connected to the lower end of the drill pipe. In drilling a subaqueous well bore from a floating vessel, problems of compensating for the weight on the bit arise due to the heaving of the vessel under conditions of tide, wind and waves. Such compensation has been accomplished through use of a slidable spline connection in the drill string above the drill collars. Although such slidable spline connection is widely used, it presents many difficulties, the principle one being the requirement that it transmit torque. When subjected to high torque, sufficient friction is developed in the splines as to render the free sliding of the joint ineffective. Moreover, such slidable spline connections have comparatively low torsional strength, resulting in their failure with attendant very high fishing costs. At times, the result of the failure has been the abandonment of the well.

Motion compensating devices have been proposed for overcoming the aforenoted difficulties, in which the drilling string is supported hydraulically by interposing a compensating apparatus between the travelling block and hook of the usual drilling apparatus employed in drilling the well bore. Such types of apparatus, and similar apparatus, are illustrated in U.S. Pats. Nos. 2,945,676, 2,945,677, 3,151,686, 3,158,206 and 3,158,208. In general, the devices illustrated therein rely upon the maintenance of a predetermined fluid pressure in a cylinder and piston mechanism by circulating hydraulic fluid under the required pressure continuously through the cylinder. The necessity for continuously pumping the hydraulic fluid at high pressure through the compensator requires a pump driven by a motor of large horsepower. So far as known, the systems illustrated in the above patents have not been used.

The problem associated with the continuous pumping of liquid through the compensator has been overcome in the system illustrated in the application of Edward Larralde and Ronald E. Beaufort, Ser. No. 69,758, filed Sept. 4, 1970, for "Hydraulic-Pneumatic Weight Control and Compensating Apparatus". In that application, a motion compensating apparatus is provided in which it is unnecessary to constantly circulate fluid through the apparatus. Instead, a gaseous medium under pressure maintains the required pressure on the hydraulic fluid in the cylinder and piston device in the absence or presence of longitudinal movement of the cylinder and piston portions of the device with respect to each other, the hydraulic fluid exerting a continuous and substantially constant stress on the running string, such as a drilling string or cable. When the apparatus is used in the drilling of a subaqueous well bore from a floating vessel, the stress exerted is a substantially constant lifting force on the drilling string, despite heaving of the drilling vessel in the water, thereby insuring the maintenance of the desired drilling weight on the drill bit secured to the lower end of the drilling string. The pressure of the gaseous medium can be varied to vary the lifting force on the drilling string, and thereby determine the drilling weight on the drill bit.

In the motion compensating system disclosed in the aforesaid application, and also in the above patents, assurance is not had that the system will consistently and closely follow movement of the floating vessel or ship. This is due to the wide range of loads carried by the compensating system and to the range of sea conditions that may prevail.

By virtue of the present invention, a sensing system is provided that forces the motion compensator to properly and closely follow ship movements. The direction and amplitude of vessel movement is transferred accurately into a mechanism that forces the members of the motion compensator to move relatively in a corresponding direction, and to the same amplitude or extent. In accomplishing this objective, the motion of the vessel with respect to a fixed reference location is utilized to provide all of the energy required for operating the sensing system, making it unnecessary for fuel to be expended in generating additional power for operating the sensing system.

In general, the sensing system includes a master mechanism operatively connected to the floating vessel and to a fixed reference point, such as a marine riser pipe secured to the ocean bottom and extending upwardly to the floating vessel. Such master mechanism is connected to a slave mechanism operatively associated with the motion compensator. Heaving movement of the vessel generates a force in the master mechanism which is transmitted to the slave mechanism to operate the latter and cause it to force the motion compensator to closely follow the movement of the vessel, both as regards its direction and extent of motion.

More specifically, the sensing system includes a master hydraulic cylinder and piston mechanism operatively connected to the vessel and the fixed reference point, and also connected to a slave hydraulic cylinder and piston mechanism connected to the motion compensator, such that liquid under pressure can transfer between the master and slave mechanism. Heaving of the vessel in one direction causes the master mechanism to impart pressure to the liquid and transfer such liquid under pressure to an appropriate portion of the slave mechanism to cause the latter to force the compensator to follow the ship movement in the proper direction. At the same time, the master mechanism is receiving fluid from another portion of the slave mechanism. Heaving of the vessel in the opposite direction causes the master mechanism to impart pressure to the liquid and transfer it under pressure to another portion of the slave mechanism, the latter forcing the compensator to follow ship movement in such opposite direction. During this time, the slave mechanism is returning liquid from its first-mentioned portion to the master mechanism. While the sensing system is operating, the compensator is fully operative to perform its compensating function, but compensates more closely for ship movement.

This invention possesses many other advantages, and has other purposes which may be made more clearly apparent from a consideration of several forms in which it may be embodied.

Such forms are shown in the drawings accompanying and forming part of the present specification. These forms 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 description is not to be taken in a limiting sense.

Referring to the drawings:

FIG. 1 is a diagrammatic view of a drilling rig mounted on a floating vessel for drilling a subaqueous bore hole, embodying the compensating and sensing apparatus illustrative of the present invention;

FIG. 2 is a diagrammatic view of the sensing and compensating portion of the apparatus disclosed in FIG. 1 on an enlarged scale;

FIG. 3 is a diagrammatic view of a compensating and sensing system embodying the present invention;

FIG. 4 is a diagrammatic view of a modified form of a portion of the motion sensing system;

FIG. 5 is a diagrammatic view of still another embodiment of the motion sensing system.

Apparatus is disclosed in the drawings in connection with the drilling of a vertical well bore W (FIG. 1) from a subaqueous floor F above which a floating vessel V, such as a drilling barge, is located, the barge being suitably anchored against lateral displacement for the purpose of holding a tubular drilling string S in a centered relation with respect to the well bore. The drilling string passes through a string of marine riser pipe M, the lower portion of which is secured to the ocean floor through other mechanisms, such as a blowout preventer stack G and a casing hanger Z. The upper portion of the marine riser pipe is constituted as a slip joint **100** extending into the vessel, the inner portion **101** of which is suitably affixed to the vessel V to move vertically therewith relative to the fixed outer portion **102** of the slip joint. A drill bit B is secured to the lower end of the drill string, such as a string of drill pipe or drill casing S, the upper kelly portion K of the drill string passing through the usual rotary table T rotated by a suitable drive mechanism (not shown). The upper end of the kelly is secured to a swivel R suspended from a hook C pivotally connected to the lower end of a compensating apparatus D, the upper end of which is pivotally connected to the travelling block E associated with the usual lines H passing over the crown block J at the upper end of the derrick L secured in place on the floating drilling vessel, the cables or lines being connected to a suitable drawworks N on the floating barge.

A suitable mud line P is connected to the swivel R for the purpose of delivering drilling mud to the drill string for discharge from the drill bit B to remove the cuttings produced by the latter while appropriate drilling weight is imposed thereon, with the drilling string being rotated by the table T at the desired speed. Usually, the drilling weight is furnished by a suitable length of drill collars disposed in the lower portion of the drill string S immediately above the drill bit, the drill string above the drill collars being maintained in tension by the drawworks N and lines H, the drawworks permitting the drill string to lower as the hole W is being produced.

As shown and described in the above application, Ser. No. 69,758, the compensating apparatus D permits the floating vessel V, and the mechanisms carried thereby, to shift vertically relative to the well bore W and drilling string S, without appreciably modifying the drilling weight imposed on the drill bit B. The floating vessel is also shiftable relative to the fixed portion **102** of the marine riser pipe string M below the inner portion **101** of the slip joint **100**. This compensating apparatus includes a lower supporting structure **10** connected to the hook C and an upper supporting structure **11** connected to the lower end of the travelling block E. In the specific form of compensating apparatus illustrated, the lower supporting structure **10** is secured to the lower ends of a pair of piston rods **12** extending upwardly into a pair of cylinders **13** affixed to the upper supporting structure **11**. The upper ends of the piston rods are secured to pistons **14** having appropriate seal rings (not shown) thereon for slidably sealing against the cylinder walls, the rod ends of the cylinders carrying appropriate packings (not shown) for slidably sealing against the periphery of the piston rods **12**. The cylinders **13** are preferably disposed on opposite sides of the travelling block E and extend thereabove to reduce the overall length of the compensating unit D.

It is evident that the travelling block E is secured to the cylinders **13**, so that the latter move vertically therewith, while the pistons **14** and the piston rods **12** are secured to the hook C, and through the swivel R to the upper end of the drill string S. The weight of the drill string is transmitted through the hook C to the piston rods **12** and pistons **14**, and then to liquid **15** filling the cylinder spaces below the pistons **14**, from where it is transmitted to the lower cylinder heads **13a** and to the cylinders **13** themselves, from where the load is transferred to the travelling block E and the lines H to the crown block J. As noted above, elevation and descent of the travelling block and, therefore, of the compensating unit D, and the entire load S suspended therefrom, is determined by the operation of the drawworks N.

A substantially constant predetermined pressure is maintained in the liquid medium **15** disposed in the cylinders. Such liquid under pressure acts in an upward direction on the pistons **14** and, therefore, on the hook C, swivel R and drill string S connected thereto. Since the weight of the entire drill string is known, the unit pressure of the liquid medium is selected such that all of such weight, with the exception of the drilling weight to be imposed on the drill bit B, which is usually the weight of the drill collars, is supported by the liquid pressure acting in an upward direction over the areas of the pistons **14**. In the particular compensating system disclosed in the drawings, this pressure is derived from a gaseous medium **16**, such as nitrogen, disposed in a bank of accumulators **17** supported on the vessel V. The rod ends of the cylinders **13** are connected to liquid lines **18** extending to a control valve **19**, from where fluid lines **20** run to the liquid ends **21** of the cylindrical accumulator members **22**. The lower portions of the accumulators are filled with liquid **15**, and the upper ends 23 are filled with the gas 16 under pressure, the gas and liquid in each cylindrical accumulator being separated by a floating piston 24 that makes a suitable slidable seal against the cylindrical wall of the accumulator housing 22. Accordingly, the gas pressure of the gas 16 is transmitted through the floating piston 24 to the liquid 15, the same liquid pressure being present in the compensating cylinders 13. Movement of the pistons 14 in the cylinders 13 is permitted, the floating pistons 24 correspondingly shifting while continuing to transmit the pressure of the gaseous medium 16 to the liquid 15 in the accumulator, and thence through the lines 20, 18 to the liquid 15 in the compensating cylinders 13.

The ability of the liquid to pass through the compensator cylinders and the accumulators is controlled by the valve 19 of any suitable type. Normally, during the operation of the compensator apparatus, the valve 19 is in its open position to permit the free transfer of liquid between the compensator cylinders 13 and the accumulator cylinders 22.

A high pressure gas supply is contained in a bank of storage tanks 29 communicating with a manifold 30, there being a shut-off valve 31 between each storage tank and the manifold. The manifold line has a valve 32 therein normally biased to a closed position by a spring 33, but shiftable manually to an open position whenever the high pressure gas is to be permitted to flow through a variable pressure regulator valve 34, discharging therefrom at the selected pressure into lines 35, 36 leading to the accumulator cylinders 22. Each line 36 leading to its associated cylinder is controlled by a valve 37 normally biased to a closed position by a spring 38, but manually shiftable to an open position to permit the gas at the regulated pressure to pass into the gas chamber 23.

While only a few accumulators 17 and storage vessels 29 are disclosed for purpose of illustration only, actually they can be supplied in any number, all connected in the system as illustrated.

The liquid medium 15 is derived from a reservoir 38a, a suction line 39 from the reservoir running to a pump 40, the discharge line 41 of which can force the liquid through a check valve 42 and through a normally closed valve 43 into the liquid line 20 communicating with the liquid containing portions 21 of the accumulator cylinders. The check valve 42 permits flow of liquid from the pump in a direction toward the accumulator cylinders 22 and the compensator cylinders 13, but will prevent reverse flow of such liquid to the pump.

If the liquid pressure were to increase above a safe maximum preset value, substantially above the normal operating pressure of the liquid, the excess pressure would bleed through the line 20*a* and through a pressure relief valve 20*b*, set at a desired value, into the reservoir 38*a*, thereby effecting a withdrawal of liquid from the hydraulic portion of the system.

A valve 31*a* may be connected to the line 30 to bleed off the pressure in the manifold when the shut-off valves 31 leading from the gas storage tanks 29 are closed, the manifold pressure being observable on a gauge 31*b*.

For a detailed illustration and description of the entire compensating system, attention is directed to the above-identified application Ser. No. 69,758. Such details are unnecessary for an understanding of the present invention.

In the operation of the apparatus illustrated in the drawings, the accumulators 17 are charged with gas 16 at the desired pressure, there being sufficient liquid in the system such that the same pressure is imposed on the liquid in the compensating cylinders 13, which exerts an upward force on the pistons 14 and on the drill string S, the supported load being carried from the cylinders 13 to the travelling block E, and from the lines H to the crown block J. Drilling proceeds through appropriate rotation of the rotary table T with drilling mud being pumped down the drilling string, returning in a known manner to the floating vessel V through the marine conductor pipe M extending from the drilling vessel V to the well bore W. In the event the floating vessel were to shift vertically, for example, rise, the cylinders 13 will move upwardly along the piston rods 14 and pistons 12, the liquid therein remaining at substantially the same pressure, merely being forced through the lines 18, 20 into the lower portions 21 of the accumulator 17, forcing the floating pistons 24 upwardly to further compress the gas 16 to a small extent, which will effect some increase in the pressure of the liquid 15; but, as a practical matter, to too small an extent as to have any significant effect on the drilling weight imposed on the drill bit B. Similarly, should the vessel V move downwardly, the cylinders 13 would move downwardly therewith, the cylinder volume below the pistons 14 increasing, the gas 16 under pressure forcing the liquid 15 from the accumulators back into the compensator cylinders 13, while maintaining the required pressure on the liquid 15. Thus, within the operative stroke of the compensator apparatus, the drilling vessel can heave upwardly and downwardly relative to the drill string S, without materially altering the drilling weight on the drill bit. The number of accumulators 17 and their combined cross-sectional areas are preferably many times the annular areas of the pistons 14, so that a large liquid volume change in the cylinders 13 produces a much smaller volume change in each accumulator or expansion space 21, thereby effecting only a relatively small movement of each piston 24 and change in the pressure of the gas in the upper portion 23 of the accumulator.

If the operator wishes to maintain the pistons 14 in an intermediate position within the cylinders 13, as, for example, midway along the length of their travel in the cylinders, he can feed off line H from the drawworks in the usual manner of drilling on land, so that the travelling block E and the compensator D are lowered to the same extent as the footage drilled. However, the operator may, if he desires, merely retain the drawworks in a set position, the pistons 14 merely lowering along the cylinders 13 as the drilling proceeds, while the pressure of the liquid 15 is maintained for the purpose of supporting the required portion of the total drilling weight of the drill string S, insuring that the remainder of such drilling weight will be imposed on the drill bit B. When the piston 14 descends sufficiently, the driller can then feed line H off the drawworks, allowing the cylinders 13 to shift downwardly along the pistons 14 and piston rods 12 once again. However, during such downward shifting, the gas 16 under pressure in the accumulator 17 will feed liquid

15 back into the compensator cylinders 13, while maintaining such liquid within the desired pressure range, to hold the drilling weight on the drill bit substantially at a constant value. Thus, it is apparent that the gas under pressure will maintain the desired liquid pressure in the cylinders 13, and that the cylinders 13 and pistons 14 can shift vertically relative to each other to compensate for the vertical movement of the floating vessel V under wind, tide and wave action. As an example, the cylinders 13 and piston rods 12 may be of such length as to permit a safe vertical movement of the floating vessel of about ten feet, with the drilling string S being maintained in tension to the desired value by the liquid 15 under pressure.

Under certain conditions, the compensator system might not follow closely the vertical movement of the vessel, there being a time lag in the relative shifting of the pistons 14 within the cylinders 13 of the compensating apparatus. Such time lag in operation may be due to a wide range of loads carried by the system and the wide range of sea conditions that might prevail.

To force the compensation apparatus D to closely follow the vertical movement of the vessel due to sea conditions, a sensing apparatus or system has been associated therewith. Such sensing apparatus will exert a force relatively shifting the compensating cylinders 13 and pistons 14 in close conformance with the extent of vertical movement of the vessel V and in the appropriate relative directions. It may be assumed that the hook C and the lower supporting structure 10, piston rods 12, and pistons 14 are to be maintained substantially stationary as regards vertical movement, despite heaving of the vessel, so that the required tension will be maintained on the string of drill pipe S. If the vessel were to move downwardly, the piston mechanism 10, 12, 14 and hook C would be forcibly held relatively at the same vertical position relative to the ocean floor F, or some other fixed reference point, such as the fixed marine riser pipe M. However, the cylinders 13 would be forced downwardly to the same extent as the vessel. Conversely, if the vessel were to move upwardly, then a force would be exerted to retain the compensating piston mechanism 10, 12, 14 and hook C carried in the same vertical position relative to the fixed or stationary reference point, or ocean bottom F, but the cylinders 13 would be forced upwardly to the same extent as the vessel.

The apparatus illustrated in FIGS. 1, 2, 3 will effect an upward or downward relative forcing of the cylinders 13 of the compensating mechanism, and parts connected thereto, in the desired direction and to the desired extent in prompt response to the heaving of the floating vessel, while exerting a force retaining the pistons 14 and hook C in a fixed vertical position. As shown, a pair of slave cylinders 200 are suitably secured to the upper supporting structure 11 on opposite sides of the travelling block E, these cylinders conforming in vertical length and position to the compensating cylinders 13. A double acting piston 201 is slidable within each slave cylinder, this piston carrying a suitable seal ring (not shown) for sealing against the wall of the slave cylinder. A lower piston rod 202 is affixed to the piston 201 and extends in slidable sealed relation through its lower cylinder head 203, being affixed to the lower supporting structure 10 that carries the hook C. An upper piston rod 204 is secured to the piston 201 and extends through the upper cylinder head 205, being in slidable sealing relation therewith. Each double acting slave piston 201 occupies the same horizontal position as the compensating pistons 14, and since the pistons 14, 201 are operatively connected to the same lower supporting structure 10, they move vertically in unison within their cylinders 13, 200.

A vertical master cylinder 210 is suitably affixed to an appropriate portion of the drilling vessel V, being movable therewith. The lower end 211 of this master cylinder is connected through suitable tubular lines 212 to the lower ends 203 of the slave cylinders 200; whereas, the upper end 213 of the master cylinder is connected through suitable fluid lines 214 to the upper ends 205 of the slave cylinders. A master piston 214^1 is shiftable vertically in the master cylinder 210, having suitable seal means thereon (not shown) that slidably seal against the wall of the master cylinder. A lower master piston rod 215 is affixed to the piston 214^1 and extends downwardly through the lower end 211 of the cylinder in slidable sealing relation therewith, there being an upper piston rod 216 secured to the piston 214^1 and extending through the upper end 213 of the cylinder in slidable sealing relation therewith. A liquid completely fills the master cylinder 210 on both sides of the double acting piston 214^1 contained therein, the fluid lines 212, 214 extending to the slave cylinders 200, and the slave cylinders themselves on both sides of the double acting pistons 201, such that movement of the master piston 214^1 in either direction is accompanied by movement of the slave cylinders 200 in the same direction and to the same extent. The area of each annular space in the master cylinder 210 surrounding each piston rod 215, 216 will be equal to the combined annular areas in the two slave cylinders around each pair of piston rods 202 or 204, in order to secure movement of the double acting slave cylinders 200 the same distance as the double acting master piston 214^1 is moved.

The master cylinder 210 is prevented from moving vertically with respect to the vessel, as by being connected thereto through a collar 222 clamped to the cylinder and a suitable strut 221 fixed to the collar and a deck 233 of the vessel. The master piston 214^1 and rods 215, 216 are caused to move relative to the master cylinder 210 the same vertical distance as the vessel V. A collar 223 is secured to the fixed riser pipe M and is connected by a pin 224 to the lower end of a connecting rod 225, the upper end of this connecting rod being mounted on a pivot pin 226 suitably affixed to a clamp 227 fastened to a chain 228. The upper portion of the chain passes over an upper sprocket 229 suitably rotatably supported on a support bracket 230 affixed to the vessel V, as to the derrick floor, the end of this chain being connected to the upper end of the master piston rod 216. Below the upper end of the connecting rod 225, the chain passes around a lower sprocket 231 suitably rotatably supported on a support bracket 232 affixed to the vessel, as to the deck 233, this chain being connected to the lower end of the master piston rod 215.

The chain 228 is connected to the stationary marine riser pipe M, so that its intermediate portion between the upper and lower sprockets 229, 231 cannot move vertically. However, vertical movement of the vessel V will produce corresponding vertical movement of the master piston rods 215, 216 and double acting piston 214^1 within the cylinder 210 in the same direction to transfer fluid between the master cylinder and the slave cylinders 200. As an example, assuming the vessel to shift downwardly in the water, the upper and lower supporting brackets 230, 232 would move downwardly therewith to correspondingly lower the upper and lower sprockets 229, 231, as well as the cylinder 210. Downward translation or lowering of the lower sprocket 231 would cause it to move downwardly along the chain 228 and effect a downward pull and movement on the piston rod 215 and double acting piston 214^1, the upper piston rod 216 also moving downwardly to maintain the required tautness or tension in the sprocket chain. Actually, the rod and piston combination 215, 216, 214^1 will move twice the vertical distance moved by each sprocket and the cylinder 210, the piston moving relative to the cylinder 210 the same distance that the vessel has moved. Downward movement of the piston forces liquid from the lower portion of the master cylinder 210 through the tubular lines 212 into the lower ends 203 of the slave cylinders 200, exerting a downward force on such cylinders and an upward force on the slave pistons 201. Accordingly, the cylinders 200 would be forced downwardly, which will correspondingly act through the upper supporting structure 11 to insure that the compensation cylinders 13 are moved downwardly to the same extent as the vessel has moved downwardly, the upward force on the double acting pistons 201 actually merely retaining the lower supporting structure 10 and the hook C in the same position that it occupied before the vessel heaved downwardly. The downward movement of the salve cylinders 200 causes the slave pistons 201 to force the liquid in the upper portions of the cylinders 200 through the tubular lines 214 into the upper end of the master cylinder 210.

Assuming the vessel were to heave upwardly, the reverse action takes place, since the upward translation of the upper sprocket 229 will act through the chain 228 passing therearound to pull upwardly on the piston rod 216 and cause the master piston 214^1 to force liquid from the upper portion 213 of the master cylinder through the lines 214 into the upper ends of the slave cylinders 200 to exert an upward hydraulic force on the slave cylinders 200 and a relative downward force on the slave pistons 201, again insuring the proper follow-up of the slave cylinders 200 and compensation cylinders 13 in an upward direction, corresponding to the upward movement of the vessel V, and the retention of the slave pistons 201 and rods 202 in the downward position, as well as the lower supporting structure 10, and the hook C connected thereto.

It is apparent that the slave cylinders 200 are hydraulically linked to the master cylinder 210 and will follow closely upward and downward movements of the master cylinder, virtually eliminating time lag in the relative movements between the cylinders 13 and pistons 14 of the compensating apparatus D. Since the motion compensating apparatus is essentially a passive system and is in equilibrium under load, the sensing system, which includes the master and slave cylinder and piston apparatus, need only provide enough force to move the compensating system an amount or distance equal to the ship movement due to its heaving.

If it is desired to shift the position of the slave pistons 201 in their cylinders 200, a cross-over line 250 can be provided interconnecting the upper and lower lines 214, 212, controlled by a valve 251, which will normally be closed and which is opened whenever repositioning of the slave pistons 201 in the slave cylinders is desired, as, for example, when the slave pistons are to be placed in a central position within their cylinders 20.

The connecting rod 225 interposed between the fixed collar 223 and the chain 228, and its pivot pin connections 224, 226 thereto, will prevent damage to the apparatus, which might otherwise arise due to tilting of the ship V.

A modified form of apparatus is illustrated in FIG. 4 with respect to the master cylinder mechanism and its connection with the marine riser pipe and the vessel. As disclosed, the master cylinder 210*a* is connected through an upper pin 260 to a connecting rod 261, the lower end of which is secured by a pivot pin 262 to a collar 263 attached to the marine riser pipe M. The master rods 215, 216 and piston 214^1 are slidable within the master cylinder, the upper end of the upper rod 216 being secured to a suitable portion of the vessel, such as the derrick floor 264, though the agency of a hinge pin 265, the lower end of the lower rod 215 being secured to a suitable portion of the vessel, such as its deck 266, through a hinge pin 267. The hydraulic lines 212, 214 are connected between the master cylinder 210*a* and the slave cylinders 200 in the same manner as in the other form of the invention, the mechanism operating in the same manner. Thus, downward movement of the vessel V will be accompanied by downward movement of the piston 214^1 within the stationary cylinder 210*a* to cause a corresponding downward force imposed on the slave cylinders 200 and upward force on the double acting slave pistons 201. Conversely, upward movement or heave of the vessel will cause the liquid to be transferred under pressure into the upper ends of the slave cylinders 200, to exert an upward force on the slave cylinders and a relative downward force on the double acting slave pistons 201.

In all respects, the embodiment illustrated in FIG. 4 operates in the same manner as in the other embodiment. In effect, the master cylinder and slave cylinder arrangements inform the motion compensator D that the vessel is moving up or down, effecting fast response in the compensator to such up and down movements, such that the compensator piston mechanism and the hook C remain in virtually a fixed vertical position with respect to a fixed reference point, such as the stationary marine riser pipe M and ocean floor F.

In the form of invention illustrated in FIG. 5, the master cylinder 210*b* is secured by a suitable connector 280 to the drilling vessel V to move vertically with respect thereto, while the master piston 214^1 has a piston rod 270 secured thereto, the lower end of which is connected by a pin 271 to the stationary marine riser pipe M. The upper portion of the master cylinder 210*b* is connected through a hydraulic line 212*a* to the lower ends of the slave cylinders 200; whereas, the lower end of the master cylinder is connected through a hydraulic line 214*a* to the upper ends of the slave cylinders. Thus, downward movement of the drilling vessel V in the water will cause the cylinder **210***b* to move downwardly along the piston 214^1 and force liquid from the upper end of the master cylinder into the lower ends of the slave cylinders **200**. On the other hand, upward movement of the drilling vessel in the water will cause corresponding upward movement of the master or active cylinder **210***b* with respect thereto, forcing the hydraulic liquid from the bottom of the master cylinder into the upper end of the slave cylinders **200**, the slave cylinders **200** and pistons **201** of the sensing system effecting immediate response of the compensator cylinders **13** in moving in the proper direction and to the same extent as the floating vessel has moved.

We claim:

1. In apparatus for maintaining a predetermined stress in a running string supported from a vessel floating in a body of water: cylinder means; piston means slidable in said cylinder means; one of said means being adapted for operative connection to the running string; the other of said means being adapted to operative connection to a supporting means on the vessel; means for maintaining a liquid medium under pressure in said cylinder means on one side of said piston means as said piston means and cylinder means move longitudinally relative to one another in both longitudinal directions; and means operable in response to vertical movement of the vessel in the water for exerting a force tending to shift said cylinder means and piston means vertically with respect to each other a distance proportionate to the vertical movement of the vessel.

2. In apparatus as defined in claim **1**; said force exerting means being operable to shift said cylinder means and piston means vertically with respect to each other in both upward and downward directions in response to upward and downward movement of the vessel in the water.

3. In apparatus as defined in claim **1**; said force exerting means being operable to shift said cylinder means and piston means vertically with respect to each other in both upward and downward directions a distance substantially equal to the extent of vertical movement of the vessel and in the same direction.

4. In apparatus for maintaining a predetermined stress in a running string supported from a vessel floating in a body of water: compensator cylinder means; compensator piston means slidable in said cylinder means; one of said compensator means being adapted for operative connection to the running string; the other of said compensator means being adapted for operative connection to a supporting means on the vessel; means for maintaining a liquid medium under pressure in said cylinder means on one side of said piston means as said piston means and cylinder means move longitudinally relative to one another in both longitudinal directions; sensing means including master cylinder means and master piston means slidable therein, slave cylinder means and slave piston means slidable therein, means supporting said master cylinder means and master piston means to effect relative vertical movement therebetween in response to vertical movement of the vessel; means operatively associating one of said slave cylinder means and slave piston means with said one of said compensator means for movement therewith; means operatively associating the other of said slave cylinder means and slave piston means with said other of said compensator means for movement therewith; and fluid conducting means conducting fluid therebetween, whereby relative motion between said master cylinder means and master piston means correspondingly shifts said slave cylinder means and slave piston means with respect to each other.

5. In apparatus as defined in claim **4**; said master cylinder means and master piston means and said slave cylinder means and slave piston means being constructed and arranged with respect to each other that both upward and downward movement of the vessel effects corresponding upward and downward movement of said other of said slave means.

6. In apparatus for maintaining a predetermined stress in a running string supported from a vessel floating in a body of water: compensator cylinder means operatively connected to a supporting means on the vessel; compensator piston means slidable in aid cylinder means and adapted for operative connection to the running string; means for maintaining a liquid medium under pressure in said cylinder means on one side of said piston means as said piston means and cylinder means move longitudinally relative to one another in both longitudinal directions; and means operable in response to vertical movement of the vessel in the water for exerting a force tending to shift said cylinder means and piston means vertically with respect to each other a distance proportionate to the vertical movement of the vessel.

7. In apparatus as defined in claim **6**; said force exerting means being operable to shift said cylinder means vertically in the same direction as the vessel moves both upwardly and downwardly.

8. In apparatus as defined in claim **6**; said force exerting means being operable to shift said cylinder means vertically in the same direction as the vessel moves both upwardly and downwardly and a distance substantially equal to the extent of vertical movement of the vessel.

9. In apparatus for maintaining a predetermined stress in a running string supported from a vessel floating in a body of water: compensator cylinder means operatively connected to a supporting means on the vessel; compensator piston means slidable in said cylinder means and adapted for operable connection to the running string; means for maintaining a liquid medium under pressure in said cylinder means on one side of said piston means as said piston means and cylinder means move longitudinally relative to one another in both longitudinal directions; sensing means including master cylinder means and master piston means slidable therein, slave cylinder means and slave piston means slidable therein, means operatively supporting said master cylinder means and master pistons means to effect relative vertical movement therebetween in response to vertical movement of the vessel; means operatively associating said slave cylinder means with said compensator cylinder means for movement therewith; means operatively associating said slave piston means with said compensator piston means for movement therewith; and fluid conducting means between said master cylinder means and slave cylinder means for conducting fluid therebetween, whereby relative motion between said master cylinder means and master piston means correspondingly shifts and slave cylinder means and slave piston means with respect to each other.

10. In apparatus as defined in claim **9**; said master cylinder means and master piston means and said slave cylinder means and slave piston means being constructed and arranged with respect to each other that both upward and downward movement of the vessel effects corresponding upward and downward movement of said slave piston means.

11. In apparatus as defined in claim **9**; said master piston means being operatively connected to the vessel; said master cylinder means being operatively connected to the fixed reference point.

12. In apparatus as defined in claim **9**; said master piston means being operatively connected to the fixed reference point; said master cylinder means being operatively connected to the vessel.

13. In apparatus as defined in claim **9**; said supporting means comprising means connecting said master cylinder means to the vessel and further including means operatively connected to a fixed reference point and to said master piston means for movement of said master piston means relative to the vessel and master cylinder means as the vessel moves vertically.

14. In apparatus for maintaining a predetermined stress in a running string extending from a vessel floating in water to a bore hole extending downwardly from a subaqueous floor, a relatively stationary marine riser extending upwardly from the region of the bore hole to the floating vessel: compensator cylinder means; compensator piston means slidable in said cylinder means; one of said compensator means being adapted for operative connection to the running string; the other of said compensator means being adapted for operative connection to a supporting means on the vessel; means for maintaining a liquid medium under pressure in said cylinder means on one side of said piston means as said piston means and cylinder means move longitudinally relative to one another in both longitudinal directions; sensing means including master cylinder means and master piston means slidable therein, slave cylinder means and slave piston means slidable therein, means operatively connecting one of said master cylinder means and master piston means to the marine riser, means operatively connecting said other of said master cylinder means and master piston means to the vessel for vertical movement therewith; means operatively associating one of said slave cylinder means and slave piston means with said one of said compensator means for movement therewith; means operatively associating the other of said slave cylinder means and slave piston means with said other of said compensator means for movement therewith; and fluid conducting means between said master cylinder means and slave cylinder means for conducting fluid therebetween, whereby relative motion between said master cylinder means and master piston means correspondingly shifts said slave cylinder means and slave piston means with respect to each other.

15. In apparatus as defined in claim **14**; said master cylinder means and master piston means and said slave cylinder means and slave piston means being constructed and arranged with respect to each other that both upward and downward movement of said other of said master means with the vessel effects corresponding upward and downward movement of said other of said slave means.

16. In apparatus for maintaining a predetermined stress in a running string extending from a vessel floating in water to a bore hole extending downwardly from a subaqueous floor, a relatively stationary marine riser extending upwardly from the region of the bore hole to the floating vessel: compensator cylinder means; compensator piston means slidable in said cylinder means; one of said compensator means being adapted for operative connection to the running string; the other of said compensator means being adapted for operative connection to a supporting means on the vessel; means for maintaining a liquid medium under pressure in said cylinder means on one side of said piston means as said piston means and cylinder means move longitudinally relative to one another in both longitudinal directions; sensing means including master cylinder means and master piston means slidable therein, slave cylinder means and slave piston means slidable therein, means operatively connecting one of said master cylinder means and master piston means to the marine riser, means operatively connecting said other of said master cylinder means and master piston means to the vessel for vertical movement therewith; means operatively associating said slave cylinder means with said compensator cylinder means for movement therewith; means operatively associating said slave piston means with said compensator piston means for movement therewith; and fluid conducting means between said master cylinder means and slave cylinder means for conducting fluid therebetween, whereby relative motion between said master cylinder means and master piston means correspondingly shifts said slave cylinder means and slave piston means with respect to each other.

17. In apparatus as defined in claim **16**; said master cylinder means and master piston means and said slave cylinder means and slave piston means being constructed and arranged with respect to each other that both upward and downward movement of said other of said master means with the vessel effects corresponding upward and downward movement of said other of said slave means.

18. In apparatus as defined in claim **16**; said master piston means being operatively connected to the vessel; said master cylinder means being operatively connected to the marine riser.

19. In apparatus as defined in claim **16**; said master piston means being operatively connected to the marine riser; said master cylinder means being operatively connected to the vessel.

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