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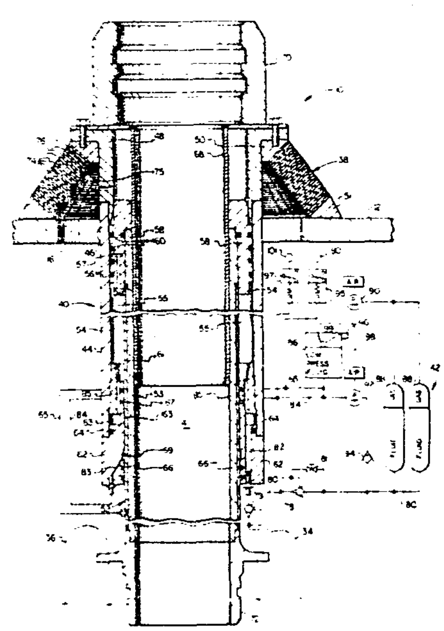
(54) **Marine riser tensioner.**

(57) Motion compensating apparatus maintains a tension load on a marine riser supported from a floating platform which is subject to movement by wave action and the like. Bending movements induced by the roll and pitch of the vessel are decoupled by a resilient bearing member (38) having an annular section of a substantially spherical or conical laminated body of superposed layers of an elastic material (74) and a relatively inelastic material (76). A tension load is applied to the riser by a hydraulic actuator (40) which is supported by the resilient bearing member (38). The actuator includes a displacement compensating cylinder chamber (55) having an adjustable volume of hydraulic fluid presented to a piston (52) in the cylinder for supporting the upper end (72) of the marine riser. The displacement of fluid in the cylinder (55) varies in response to the heave of the vessel to maintain a positive lifting force on the marine riser. An accumulator assembly (88) is connected to the pressure chamber (55) of the hydraulic actuator for supplying hydraulic fluid to and for receiving hydraulic fluid from the pressure chamber in response to changes in its volume. Hydraulic fluid leakage past the actuator seals (56 60, 67, 68) is monitored through a fluid circuit (65, 84) including pressure switches (95, 97) and leakage flow indicators (103, 101).



EP 0 088 608 A2

MARINE RISER TENSIONER

The present invention relates generally to offshore production equipment and in particular to motion compensating apparatus for use on a floating platform for supporting a marine riser extending to the platform from the ocean floor.

In performing both drilling and production operations on an offshore well, it is necessary to provide a riser connection between the sea floor and a surface facility to provide a stable conduit through which a drill string, production fluids and electrical power may be conveyed between the ocean floor and the surface facility. The surface facility may be a tanker, a drill ship, a barge, a floating platform or a platform which is fixed to the ocean floor. The riser must be supported at or near the water surface to prevent collapse. This is easily accomplished when the surface facility is a platform which is fixed to the ocean floor, but a more difficult problem is presented when the water depth is so great that the surface facility must be floating and hence is not stationary.

In regard to risers which are connected to floating structures, substantial forces act on the riser which, if not properly compensated for, will result in its failure. Of particular concern is the excessive strain which is applied to the riser as the result of upward and downward heave motions of the vessel in response to wave action. Additionally, the riser is subjected to considerable stress induced by water currents which pass around the riser but which have no particular detrimental effect on the platform. In this situation, the riser string tends to be distorted as it is displaced laterally in one or more directions in response to the underwater currents. A further problem associated with supporting a production riser from a vessel such as a floating platform or the like is the bending stress induced in the riser by the roll and pitch of the vessel. The combination of the induced bending stress and the compressive forces which are exerted by the support vessel in response to wave action will cause rapid destruction of the riser unless the destructive effects are compensated or offset in some way.

Riser tensioner systems have been developed for offshore drilling and production activities to compensate for the rise and fall of a floating platform. Such tensioner systems have commonly comprised hydraulic compensating cylinders connected by cables to the riser at symmetrically arranged tie points. In the course of their travel from cylinders to a riser, the cables pass over one or more sheaves and hence are subject to wear. It thus becomes necessary to periodically adjust the cables so that unworn portions of the cable are shifted to the sheave locations and from time to time the cables must be replaced, typically at thirty day intervals. To make this cable replacement and cylinder repair possible, a duplicate riser tensioner system with independent riser connections has normally been installed as a backup. Such an arrangement could be used on a floating production platform, but the cable wear problem is more pronounced because the productive life of the well is substantially longer than the typical drilling time of the well. Therefore, it would be desirable to provide a riser tensioner system in which the cable replacement problem is eliminated.

The problem of bending stresses induced by roll and pitch movements of the vessel have been minimized in the past by designing special support vessels and platforms which do not react significantly to wind and wave action, and also by limiting the water depth in which these vessels operate. Other approaches have attempted to decouple detrimental ship motions by providing a reliable riser connection which will tend to minimize the rigidity of the riser structural attachment to the surface vessel. The pitch and roll of the vessel, when added to the angle associated with maximum horizontal excursion of the production riser due to the ocean currents, result in excessively high bending stresses in the riser at the point of attachment unless these forces are decoupled in some way.

The most common solution to the elimination of excessively high bending stresses in the riser at the point of attachment is the provision of a riser pin connection with the surface vessel. Other arrangements have utilized a two axis gimbal connection. The use of pin and gimbal connection arrangements has been limited generally to relatively short lengths of production risers operating in relatively calm waters. However, as the search for petroleum resources advances into deeper waters requiring increased length of production risers and where more severe wave action induces higher roll, pitch and heave reactions in the support vessel, it becomes imperative to provide improved connection means for minimizing the bending action induced in the production riser string, while also minimizing the axial stresses induced into the riser string by the upward and downward heave motions of the support vessel.

It is an object of the present invention to provide a marine riser tensioner system in which cables and sheaves are not utilized.

It is a further object of the present invention to provide a load supporting resilient bearing apparatus for minimizing the bending stresses induced into a pipe string by the pitching and rolling movements of a floating vessel from which the pipe string is supported.

According to an important aspect of the invention, the invention may be practiced in combination with a floating platform or vessel of the type including a deck and having a well opening extending through the deck to provide access to the ocean beneath the platform. The invention is embodied in motion compensating apparatus which includes displaceable means engageable between the deck of the vessel and the pipe string and operable for varying the distance between the vessel and the pipe string. Passive means are coupled to the displaceable means for operating the displaceable means to maintain a positive lifting force on the pipe string as the vessel is displaced vertically relative to the pipe string. A resilient bearing member is disposed intermediate the vessel and the displaceable means with the resilient bearing member being coupled in supporting engagement with the displaceable means for permitting angular displacement of the vessel relative to the pipe string in response to roll and pitch movements imparted to the vessel by wave action, while reacting both radial and axial loads.

In a preferred embodiment, the displaceable means comprises a linear hydraulic actuator which includes a cylindrical housing and a cylindrical piston having a first end or rod portion for attachment to the pipe string and a second end or head portion movably disposed in the housing and defining a fluid pressure chamber that changes in volume as the piston is displaced relative to the housing. Accumulator means are connected in fluid communication with the pressure chamber for supplying hydraulic fluid to and for receiving hydraulic fluid from the pressure chamber in response to changes in its volume. A source of compressed gas is connected in fluid communication with the accumulator means for maintaining the hydraulic working fluid under pressure in the chamber as the platform rises and falls in response to tidal or wave movements of the ocean. Hydraulic fluid leakage past the primary piston and rod portion seals or packings is conducted through separate fluid lines to a low pressure fluid reservoir. Seal leakage is monitored by pressure switches and associated indicators connected to the leakage flow return lines.

According to another important aspect of the invention, the aforementioned resilient bearing member comprises an annular section of a substantially spherical laminated body of superposed layers of an elastic material and of a relatively inelastic material for reacting radial and axial loads. Thus the resilient bearing member cooperates with the displaceable means to relieve axial stresses as well as decoupling bending moments.

In the preferred embodiment of the invention, the hydraulic actuator comprises a cylinder member or housing projecting through a central opening of the resilient bearing member and having an annular piston slidably disposed within the housing. The annular volume intermediate the piston and housing defines a fluid pressure chamber which changes in volume with displacement of the piston relative to the housing so that the piston and the riser, which is attached to the piston, is supported on an annular column of hydraulic fluid. One important advantage of the piston and cylinder arrangement is that the high pressure hydraulic fluid supply lines are connected to the member or housing cylinder and therefore are normally not required to move and flex as the piston is extended and retracted, thereby improving the reliability of the system. However, in the event of high pressure fluid supply line breakage, fluid is prevented from being lost through the broken lines by an improved arrangement of back to back pilot operated check valves of the so called velocity fuse type. A further advantage of the abovementioned piston and cylinder arrangement is that drill tubing or other production equipment may pass directly through the piston of the actuator and through the central opening of the resilient bearing member for direct connection to a diverter assembly or to the other production equipment without the interference associated with the complex cables and sheave arrangements of prior art tensioner systems.

The foregoing as well as other objects, advantages and features of the invention will hereinafter become apparent to those skilled in the art, and for purposes of illustration, but not of limitation, an exemplary embodiment of the invention is shown in the various views of the appended drawings, in which:

Figure 1 is an elevation view of motion compensating apparatus embodying the present invention in association with a floating production platform;

Figure 2 is an enlarged front elevation view, with parts shown in longitudinal section, of the motion compensating apparatus of Figure 1;

Figure 3 is a sectional view of a portion of the resilient bearing member of the motion compensating apparatus taken along the line 3-3 of Figure 1; and

Figure 4 is a graphical illustration of the relationship between the force exerted by the motion compensating apparatus with respect to [illegible] of the platform relative to a mean position.

Referring now to Figure 1, the motion compensating apparatus of the present invention is indicated generally at 10 and is mounted on the deck 12 of a surface facility such as a floating oil well production platform indicated generally at 14. The surface facility 14 has an opening 16, extending through the deck 12, to provide access to a production riser 18 extending thereto from the ocean floor 20. It will be apparent to those skilled in the art that the surface facility 14 is not limited to a floating platform but may be any such floating structure such as a drill ship, a tanker, or a barge. However, for purposes of illustration of the invention, the motion compensating apparatus will be described in connection with a floating platform. It should also be appreciated that the motion compensating apparatus 10 has utility for use in connection with drilling, servicing or production operations in which a marine riser is employed.

The deck 12 is supported above the surface 22 of the ocean by means of a plurality of downwardly extending controllably buoyant members or legs 24 which maintain the deck 12 at a desired elevation above the ocean surface 22. The buoyant members 24 have sufficient tank capacity that the deck 12 can be raised or lowered as desired by use of a suitable control system for transporting the structure at minimum draft while in transit or for positioning it at a working draft over a production site. While not shown in detail, the respective buoyant members 24 are further provided with an interconnecting truss structure 26 and other necessary understructure for stabilizing the platform. To further stabilize the floating platform 14, a plurality of mooring lines and anchors (not shown) may be provided for holding the platform over a production site 28. An example of such an arrangement is illustrated in U.S. Patent 3,983,706.

Basic wellhead equipment 30 is shown imbedded in the ocean floor 20 beneath the platform 14. The production riser 18 extends from the wellhead equipment 30 to a conventional marine riser [illegible] 32 which is provided with flex joints and integral choke and kill lines 34, 36. The usual Christmas tree arrangement and control member, although not shown, may also be included in the wellhead equipment 30 to control the production operation insofar as production fluid flow is concerned. The lower end of the riser 18 is preferably pivotally connected to the wellhead 30 to allow for a limited amount of relative movement as the platform 14 is subjected to some lateral displacement from its desired location above the production site 28.

The production riser 18 typically comprises a number of elongated tubular members connected end to end and having sufficient diameter to enclose drill tubing and to conduct drilling mud. A typical cross-sectional dimension of the riser is sixteen inches O.D. with one-half inch wall thickness. For production operations it is used for conveying crude oil or gas from the wellhead equipment 30 to the platform 14 where it is discharged into a reservoir carried by the platform or into a tanker (not shown) lying alongside.

As discussed above, prior art marine riser structures are subject to buckling forces induced by the heaving action of the floating platform 14 and are also subject to bending moments induced by the roll and pitch movements of the platform. The harmful effects of the bending moment and buckling forces are intensified when the platform 14 is laterally displaced excessively, and subjected to extreme vertical movement due to severe weather conditions on the water surface, for example. These problems are overcome in the present invention by the provision of the motion compensating apparatus 10 which includes a resilient bearing member 38 which reacts both radial and axial loads and decouples the roll and pitch movements of the floating vessel with respect to the production riser 18, and by the provision of a linear hydraulic actuator assembly 40 which is connected to a pneumo-hydraulic accumulator for maintaining hydraulic working fluid under pressure in the actuator assembly as the platform heaves and falls in response to wave movements of the sea. According to this arrangement, the production riser 18 is supported by a column of pressurized hydraulic fluid whose volume varies in proportion to the displacement of the floating platform 14 relative to the end of the production riser 18.

The construction details of the motion compensating apparatus 10 are illustrated in Figure 2 of the drawing. The linear hydraulic actuator assembly 40 includes a cylinder member comprising a housing 44 having a first open end portion 46 suitably connected to an annular collar 48. The collar 48 includes a cylindrical mounting flange portion which is bolted to a mounting weldment or ring 50 of the resilient bearing member 38. The actuator assembly 40 includes a cylindrical annular piston member 52 which is concentrically disposed for extension and retraction within the housing 44. The piston member 52 has a tubular piston rod portion 53 of relatively smaller diameter than the bore 54 of housing 44, thereby defining an annular pressure chamber 55 which changes in volume as the piston is displaced along the longitudinal axis of the housing. The piston 52 includes a head 58 formed as a separate part which is threadedly connected to the upper end of the rod 53. The piston head 58 includes primary seals or packings 56 and secondary packings 60 which are disposed in annular grooves formed in the head for sliding engagement with the cylinder bore 54. A circumferential fluid leakage flow groove 57 is formed in the head 58 between the packings 56 and 60 and is in communication with an elongated passages 61 formed in the rod portion 53. The passage 61 may be formed as a groove in the rod portion 53 which is closed by a sleeve 63 disposed over the outer diameter of the rod portion as shown. The passage 61 is in communication with a flexible leakage flow return line 65 by way of a suitable fitting, as shown.

The piston rod portion 53 extends through an end cap 62 threadedly secured to the lower end 64 of the housing 44 and is in fluid sealing engagement with primary seals or packings 67 and secondary packings 66. An annular groove 69 is formed in the inner bore wall of the cap 62 for conducting primary packing leakage fluid to a flexible return line 84. The cylinder end cap 62 is threadedly connected to the lower end 64 of the housing 44 in sealing engagement therewith.

The piston 52 is displaceable along the longitudinal axis of the housing 44 and is slidable with respect to an elongated tubular sleeve 68 which is concentrically disposed within the piston and suitably secured to the annular collar 48. Also secured to the collar

48 is a connector portion 70 for engaging a corresponding connector of a conventional diverter assembly (not shown). Connection to the opposite end of the motion compensating apparatus is provided by a connector portion 72 threadedly secured to the lower end of the piston rod 53. The connector 72 is adapted to be connected to the marine riser connector 32. The piston 52 and sleeve 68 cooperate to form an elongated central passage 44 extending through the apparatus 10 from the connector 70 to the connector 72.

The linear hydraulic actuator assembly 40 is supported from the deck 12 of the floating platform 14 by the resilient bearing member 38 which is disposed in load supporting relation intermediate the deck 12 and the annular collar assembly 48. The bearing member 38 is an annular section of a substantially spherical laminated body of superposed layers of an elastic material 74 and of a relatively inelastic material 76 as can best be seen in Figure 3 of the drawing. The laminated body is interposed between the mounting ring 50 and a supporting base member 51 disposed on the deck 12. A central, somewhat conical shaped passage 45 is formed axially through the bearing member 38 for receiving the collar 48 whereby the actuator 40 extends downwardly through the bearing member and the deck 12.

The purpose of the resilient bearing member 38 is to permit angular displacement of the floating platform 14 with respect to the hydraulic actuator assembly 40 and the riser 18 and, in particular, to decouple the bending moment forces which would otherwise be imparted to the riser 18 as the platform 14 rolls and pitches in response to wave movements of the sea. The elastic layer 74 is preferably formed of an elastomer material such as rubber and the relatively inelastic layer 76 is preferably formed of a metal such as steel which in combination are capable of supporting a working compressive load in excess of the production riser weight. The resilient bearing member 38 can react axial as well as radial loads, thereby cooperating with the linear actuator assembly 40 to relieve stresses induced by heaving and lateral displacement of the platform 14. In a preferred embodiment, the resilient bearing member 38 is designed to support an axially applied load of 350,000 pounds and is able to withstand a full plus or minus seven degree rotation about a radial axis for a minimum of 1.5 million cycles. The spring constant of the resilient bearing member 38 can be varied somewhat by increasing or decreasing the amount of resilient material in the layer 74.

According to a preferred embodiment of the linear hydraulic actuator assembly 40, it is designed to exert a force of 350,000 pounds at a hydraulic fluid pressure of 2,200 psi. The maximum recommended operating pressure is 2,650 psi. The cylindrical housing member 44 and piston 52 are preferably constructed from a low carbon steel which is suitable for low temperature service. The piston 52 preferably has a maximum stroke of 18 feet and is adapted to be driven at a rate of 0.6 feet per second. The force, stroke and displacement rate may, of course, vary according to the requirements of a particular application.

The annular fluid pressure chamber 55 is supplied with hydraulic fluid by a pump 92 and an accumulator assembly 42 through a flexible supply line or hose 80. High pressure working fluid is preferably conveyed through multiple runs of hydraulic hoses 80 to provide redundancy, although only one hose is shown in the drawing figures. The hoses 80 are preferably provided with back to back flow rate limiting or velocity fuse type check valves 78 and 79 as shown schematically in Figure 2. The valves 78 and 79 are operable to close in response to a break in the line 80 to prevent fluid from escaping from the chamber 55 or from being totally discharged from the supply circuit including the pump 92 and accumulator assembly 42. A manually operable valve 81 is connected across check valve 78 for repressurizing a repaired or replaced hose so that the valve 78 may be reopened without depressurizing the fluid supply circuit. High pressure hydraulic fluid is conducted through the line 80 into an inlet passage 82 in end cap 62 which leads to the annular fluid pressure chamber 55 by way of an annular chamber 83 and fluid passages 85.

According to operation of the hydraulic actuator assembly 40, the accumulator assembly 42 is suitably charged to place the riser 18 under a predetermined level of tension. The pneumo-hydraulic accumulator assembly 42 includes a plurality of hydraulic pressure tanks 88 which are adapted to receive a variable volume of hydraulic working fluid and to be charged with air or an inert gas from a [illegible] source such as an air pump [illegible]. The air or gas pressure is regulated to a substantially constant value and may also be provided by a series of compressed air or gas bottles (not shown).

In operation, the linear hydraulic actuator assembly 40 is charged with hydraulic fluid to place a predetermined level of tension, for example 250 kips, on the riser 18. As the floating platform falls in elevation with respect to the production riser 18 in response to wave movement or tidal action, the housing 44 is displaced downwardly with respect to the piston 52. The volume of the pressure chamber 55 increases proportionately and the pressure of the working fluid contained therein tends to diminish but the check valves 78 and 79, which are suitably biased to be normally open, admit high pressure hydraulic working fluid from the accumulator assembly 42 into the inlet passage 62 by way of line 80. By this operation, the pressure chamber 55 is maintained filled with high pressure hydraulic working fluid at a substantially constant pressure whereby the piston 52 and production riser 18 are supported by a column of hydraulic fluid which increases and decreases in its longitudinal extent as the housing member 44 is displaced by the heaving action of the floating platform. When the platform is being displaced in an upward direction relative to the riser string, the working fluid contained within the pressure chamber 55 is discharged back through the line 80 by way of the normally open valves 78 and 79 into the accumulator tanks 88.

The hydraulic fluid supply circuit further includes a reservoir 86 connected to the inlet port of the pump 92 for supplying makeup fluid through a check valve 94 to the system including the accumulator tanks 88. The reservoir 86 includes a float switch assembly 96 connected to a source of pressure air for operating the pump 92 when a float 99 senses a predetermined level in the reservoir.

The leakage flow return lines 65 and 84 are connected to the reservoir by way of the inlet line for pump 92, as shown. The leakage flow return lines 65 and 84 are also connected to respective pressure switches 95 and 97 which, in turn, are operable to energize respective indicators 103 and 101 if the fluid flow through the lines 65 and/or 84 should exceed a predetermined rate. Accordingly, imminent failure of the primary packings 56 and 67 may be detected and corrective action taken before the actuator assembly 40 suffers a total loss of fluid from the chamber 55.

Dynamic operation of the hydraulic actuator assembly 40 is illustrated in Figure 4 of the drawing, where the force variation exerted by the actuator is shown graphically as a function of the ship position with respect to an arbitrary reference level which corresponds to a predetermined tension level. The force variation exerted by the actuator 40 for a 92 cubic foot accumulator is shown by the graph 100 and the corresponding force variation for a 183 cubic feet accumulator is shown by the graph 102. These graphs indicate that as the capacity of the accumulator system increases, proportionately less cylinder force variation is experienced for a given change in platform position.

The present invention provides a versatile and robust motion compensating apparatus for maintaining a substantially constant tension load on a production riser while substantially reducing the bending stresses induced in the riser by the roll and pitch of the platform to which it is attached. These advantages are made possible by the resilient bearing arrangement in combination with the linear hydraulic actuator assembly. This motion compensating arrangement therefore permits various activities to be carried out at greater ocean depths and in heavier seas than has been possible with conventional motion compensating arrangements.

The particular details of construction disclosed herein are, of course, only illustrative.

CLAIMS

1. Motion compensating apparatus useful for maintaining a tension load on a pipe string supported from a relatively movable platform such as a floating vessel subject to movement by wave action and the like, the apparatus comprising:

displaceable means engageable between the vessel and the pipe string and operable for varying the distance between the vessel and the pipe string;

passive means coupled to the displaceable means for actuating the displaceable means to maintain a positive lifting force on the pipe string as the vessel is displaced vertically relative to the pipe string; and

a bearing member disposed intermediate the vessel and displaceable means, the bearing member having a resilient portion for reacting radial loads coupled in supporting engagement with the displaceable means for permitting angular displacement of the vessel relative to the pipe string in response to roll and pitch movements imparted to the vessel by the wave action.

2. The motion compensating apparatus as defined in Claim 1 wherein:

the pipe string is a marine riser of the type enclosing a central passage through which production equipment is extended from a production site to a floating vessel, the displaceable means comprising a linear hydraulic actuator having a hollow housing and a hollow piston concentrically disposed within the housing and defining an annular fluid pressure chamber intermediate the housing and piston, the space enclosed within the interior of the hollow piston defining a central passageway through which the production equipment may be extended.

3. The motion compensating apparatus as defined in Claim 1 wherein:

the bearing member comprising an annular section of a substantially spherical laminated body of superposed layers of an elastic material and of a relatively inelastic material, the annular section defining a central passageway through which the production equipment may be extended.

4. The motion compensating apparatus as defined in Claim 1 wherein:

the passive actuating means comprising a hydraulic accumulator assembly connected in fluid communication with the pressure chamber for supplying hydraulic fluid to and for receiving hydraulic fluid from the pressure chamber in response to a change in its volume.

5. The motion compensating apparatus as defined in Claim 4 wherein:

the hydraulic accumulator assembly includes fluid accumulator means for storing pressurized hydraulic working fluid and a source of compressed gas connected in fluid communication with said accumulator means for providing a predetermined fluid pressure of the hydraulic working fluid in the cylinder.

6. The motion compensating apparatus as defined in Claim 2 wherein:

said piston is sealingly engaged with said housing to form the pressure chamber by respective sets of primary and secondary seal means, each of said sets of seal means including passage means interposed between said primary seal means and said secondary seal means for conducting fluid leakage flow from said actuator to a fluid circuit including a reservoir, and indicator means in said circuit for detecting excessive fluid leakage flow through said primary seal means.

7. The motion compensating apparatus as defined in Claim 6 wherein:

a hydraulic pump is provided for charging a portion of the fluid circuit, the pump being connected to a reservoir, and the reservoir includes a float switch connected to a source of power for energizing the pump to recharge the portion of the fluid circuit including the hydraulic actuator when the fluid in the reservoir reaches a predetermined level.

8. The motion compensating apparatus as defined in Claim 4 wherein:

said accumulator assembly is connected to said pressure chamber by conduit means including flow rate limiting valve means operable to shut off fluid flow out of said pressure chamber and said accumulator assembly in response to a loss of fluid from said conduit means.

9. Motion compensating apparatus for supporting a load from a platform which is subject to vertical, roll and pitch movements comprising, in combination:

a linear actuator including a housing member and a piston member movable relative to the housing member, the piston member being coupled in supporting engagement with the load;

a bearing member disposed intermediate the platform and linear actuator and connected in supporting engagement with the housing member, the bearing member having a resilient portion for reacting radial and axial loads for permitting angular displacement of the platform while cooperating with the linear actuator to relieve axial stresses caused by vertical movement of the platform relative to the load; and

means coupled to the linear actuator for driving the piston member in opposition to vertical movement of the platform relative to the load.

10. In combination:

a resilient bearing member comprising an annular section of a substantially spherical laminated body of superposed layers of an elastic material and of a relatively inelastic material;

a hydraulic actuator supported by said resilient bearing member comprising a cylindrical housing connected to said bearing member and a cylindrical piston slidably disposed within said housing, the piston and housing defining an annular fluid pressure chamber which changes in volume with displacement of said piston relative to said housing; and

accumulator means connected in fluid communication with the pressure chamber for supplying pressurized hydraulic fluid to and for receiving hydraulic fluid from the pressure chamber in response to changes in its volume.

11. Heave compensation apparatus for supporting a load beneath a floating vessel comprising a linear hydraulic actuator including a housing and a piston having a first end portion for attachment to the load and a second end portion movably coupled to the housing defining a fluid tight, annular pressure chamber intermediate the piston and housing and changes in volume as the piston is displaced relative to the housing; accumulator means connected in fluid communication with the pressure chamber for supplying hydraulic fluid to and for receiving hydraulic fluid from the pressure chamber in response to a change in its volume; a source of compressed gas connected in fluid communication with the accumulator means for applying pressure to the hydraulic fluid in the accumulator; and, a bearing member for attachment to the vessel being coupled in supporting engagement with the actuator housing, the bearing member having a resilient portion for reacting radial and axial loads for permitting angular displacement of the floating vessel while cooperating with the linear hydraulic actuator to relieve axial stresses induced in the load by the movement of the vessel relative to the load.

12. In an offshore production facility of the type including a floating platform situated above a production site on the ocean floor and a marine riser extending from the production site to the floating platform, the marine riser enclosing a central passageway through which production equipment is extended for connection to production equipment carried by the floating platform, the combination with the marine riser of a linear hydraulic actuator having a hollow housing coupled to the floating platform and a hollow piston coupled to the marine riser and concentrically disposed for longitudinal movement within the housing defining a fluid pressure chamber in the annular space intermediate the housing and piston, the space enclosed within the interior of the hollow piston communicating with the riser passageway and defining a central passageway through which the production equipment may be extended, and a hydraulic accumulator connected in fluid communication with the fluid pressure chamber for maintaining hydraulic working fluid under pressure in said chamber as said platform heaves and falls in response to wave movements of the ocean.

13. In an offshore production rig of the type including a surface facility situated above an ocean floor production site and a marine riser extending from the production site to the surface facility, the marine riser enclosing a central passageway through which production equipment is extended for connection to production equipment carried by the surface facility, the combination with the marine riser of a bearing member resiliently coupling the marine riser to the surface facility, the bearing member having a resilient portion for reacting radial and axial loads for permitting angular displacement of the surface facility relative to the marine riser in response to roll and pitch movements of the surface facility.

14. The combination as defined in Claim 13, the bearing member comprising a laminated body of superposed layers of an elastic material and of a relatively inelastic material.

15. The combination as defined in Claim 13, wherein the bearing member is characterized by an annular section of a substantially spherical laminated body of superposed layers of an elastic material and of a relatively inelastic material, the annular section defining a central opening communicating with the riser passageway through which the production equipment may be extended.

16. In combination:

a floating platform having an opening for providing access to the water beneath the platform;

a cylindrical housing projecting through said opening having a first open end portion disposed above said platform and a second open end portion disposed below said platform;

a cylindrical piston concentrically disposed within said housing defining an annular fluid pressure chamber radially intermediate the piston and housing, said piston having a first open end portion disposed within said housing and having a second open end portion projecting through said second open end of said housing;

a first annular seal disposed intermediate said piston and said housing, said seal being secured to said first open end portion thereby providing a movable fluid barrier for containing pressurized hydraulic fluid in said pressure chamber as said piston is displaced within said housing in response to a change in pressure of said hydraulic fluid;

a second annular seal disposed intermediate said piston and said housing, said second annular seal being secured to the second open end portion of said cylindrical housing thereby providing a fixed fluid barrier for containing pressurized hydraulic working fluid in said chamber as said piston is displaced within said housing in response to a change in pressure of said fluid;

a load disposed in the water beneath said platform, said load being connected to the second open end of said piston;

a bearing member disposed intermediate the platform and said housing and in load supporting engagement with said housing for permitting angular displacement of said platform relative to said housing as said platform rolls and pitches in response to wave movements of the water; and

means connected in fluid communication with said fluid pressure chamber for maintaining hydraulic working fluid under pressure in said chamber as said platform heaves and falls in response to wave movements of the water.

17. Motion compensating apparatus for supporting a marine riser of the type enclosing a central passage through which production equipment is extended from a production site to a floating surface facility comprising, in combination:

a resilient bearing member for mounting on the surface facility characterized by an annular section of a substantially spherical laminated body of superposed layers of an elastic material and of relatively inelastic material, the annular section defining a central passageway through which the production equipment may be extended;

a hydraulic linear actuator supported by the resilient bearing member including a hollow cylindrical housing connected to the bearing member and projecting through the central passageway of the bearing member, a hollow cylindrical piston of relatively smaller diameter having a first end portion concentrically disposed within the cylindrical housing and having a second end portion for connection to the riser, the annular space intermediate the cylindrical housing and cylindrical piston defining a fluid pressure chamber which changes in volume with axial displacement of the housing relative to the piston, the space enclosed within the interior of the hollow cylindrical piston defining a central passageway through which the production equipment may be extended, and sealing means disposed in the fluid pressure chamber for containing pressurized hydraulic fluid in the pressure chamber as the piston and housing are displaced relative to each other; and

accumulator means connected in fluid communication with the fluid pressure chamber for maintaining hydraulic fluid contained therein under pressure as the surface facility heaves and falls in response to wave movements.

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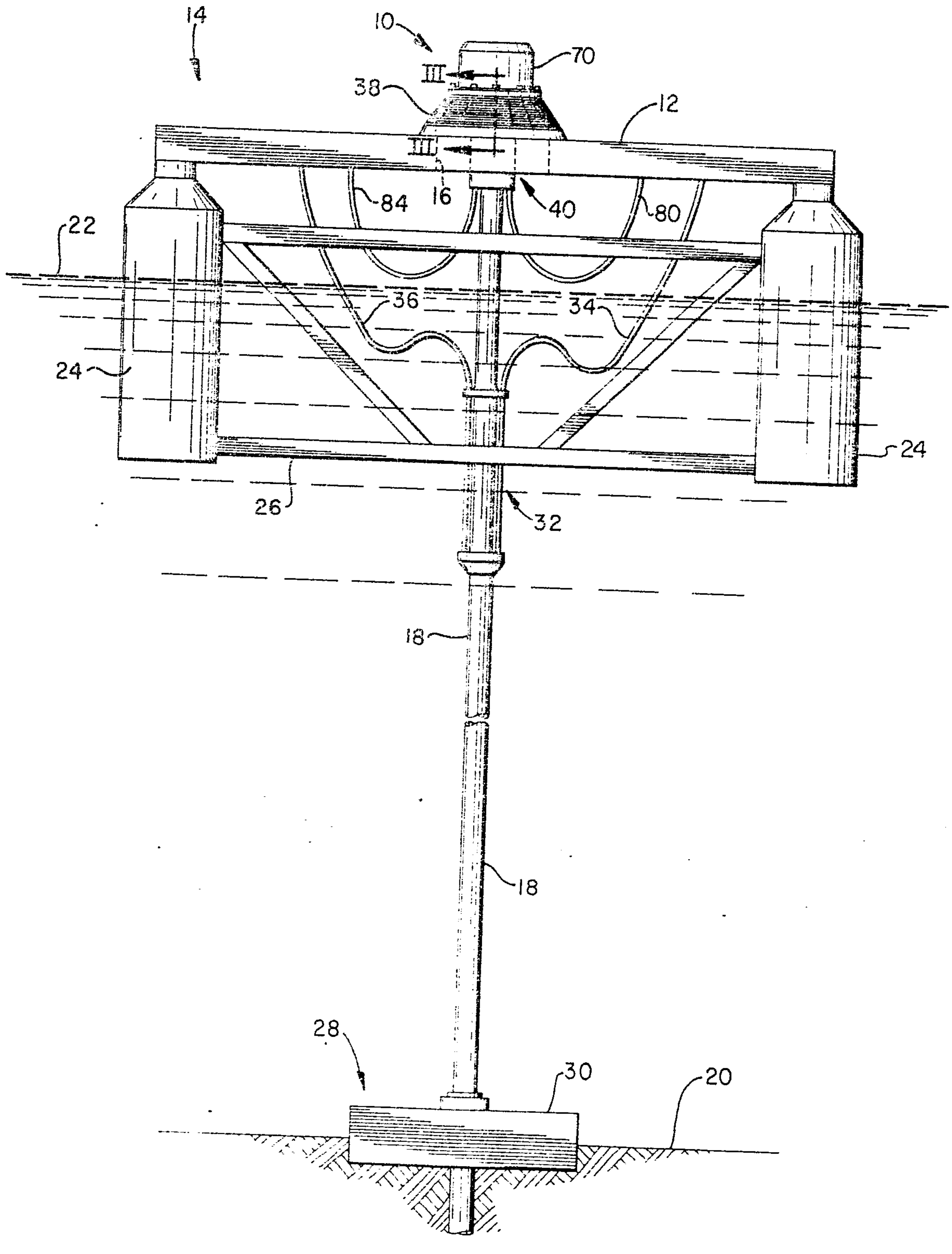
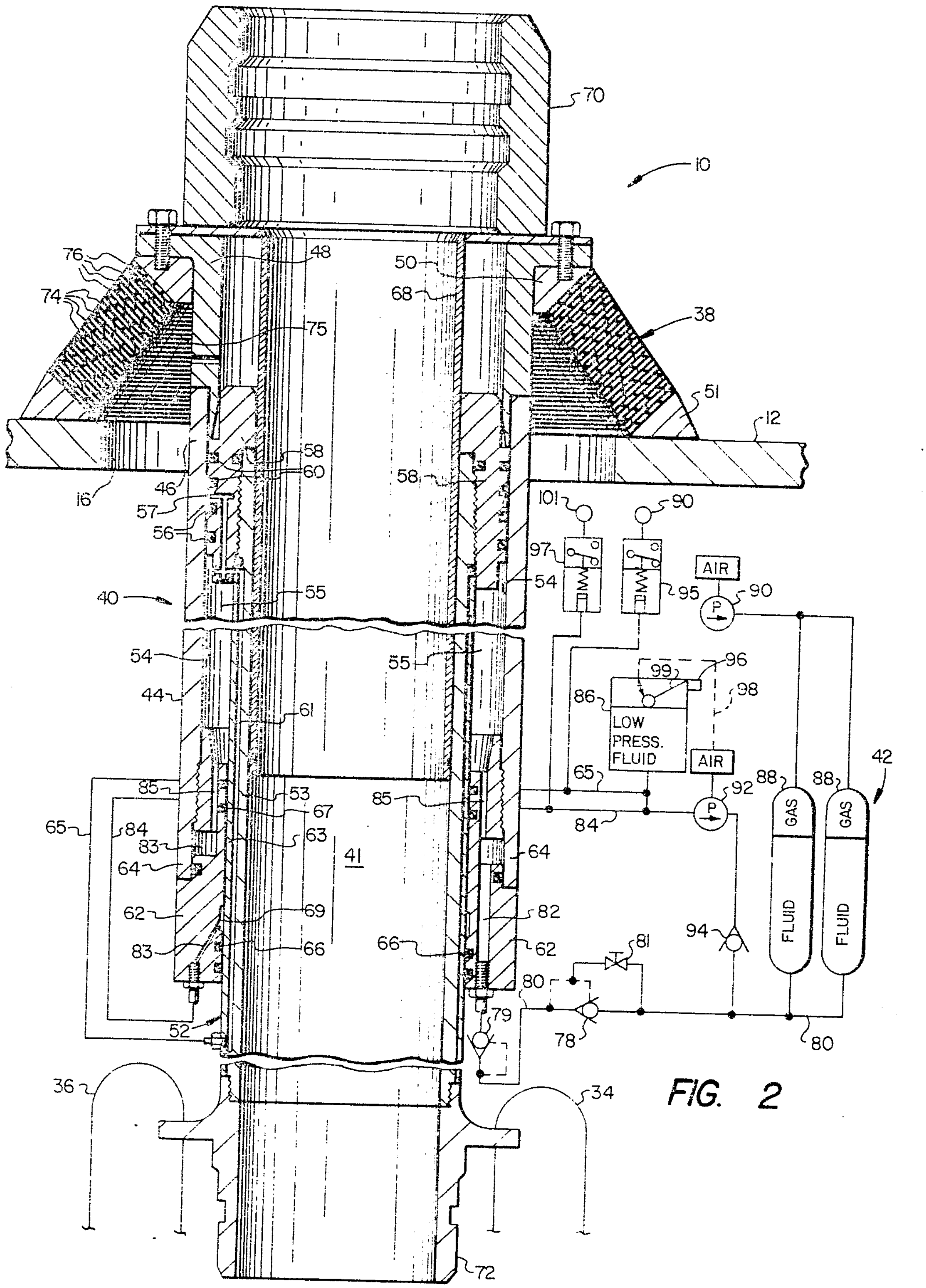
FIG. I

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GAS
FLUID
94
81
80
78
79
52
36
34
72

FIG. 2

0088608

FIG. 3

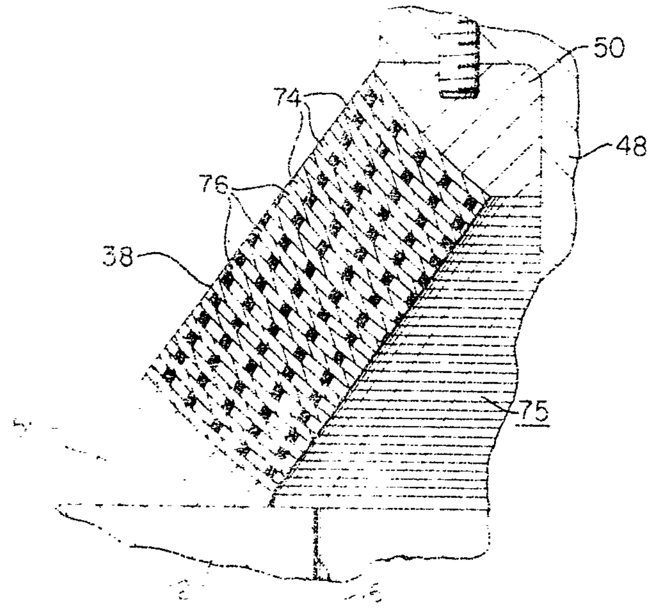

FIG. 4