The underwater petroleum well being drilled includes a marine environment-excluding tubular riser system extending from the subaqueous floor to the drilling platform. The riser system may include a blowout preventer near the floor and a telescoping joint near the surface. The riser system is maintained in tension from the platform. At least one gimbal joint is provided in the riser system, allowing relative angular movement of the system portions thereabove and therebelow. Load cell means mounted on the joint control deflection thereof, prevent snaking and tend to return the riser to an undeflected condition.

The foregoing abstract is not intended to be a comprehensive discussion of all of the principles, possible modes or applications of the invention disclosed in this document and should not be used to interpret the scope of the claims which appear at the end of this specification.

BACKGROUND OF THE INVENTION

Offshore drilling of petroleum wells is usually conducted from a stable platform such as a platform rigidly supported from the ocean floor or a floating platform, for instance on a barge or ship. Especially in the case of floating platforms, it is desirable to drill the well with blowout preventers mounted near the ocean floor and to communicate the well to the rig during drilling via a marine riser, a universal joint and slip joint. It is conventional to place one or more remotely disconnectable connectors in such riser systems. Accordingly, the preventers and wellhead are protected against damage should wind and wave action move the drilling vessel from location or disturb the position of the stable platform from which drilling is being conducted.

Of the universal joints which have been previously proposed for use in such marine riser systems, ball joints and flexible pipe sections have predominated. One drawback of many ball joints is that the ball and its socket provide both primary sealing and primary support at the same surface locations on the respective elements. Thus excessive wear and seal disruption may occur at these surfaces. Flexible pipe sections, especially those which include interlocked stacks of annuli of composite metal and rubber elements, also wear excessively and may "snake" during use, sufficiently to cause equipment to become stuck in the well or damaged due to intricate bending that such equipment cannot tolerate.

A discussion of certain problems encountered in drilling from a floating vessel is provided in the U.S. patent of Postlewaite et al. 3,513,338.

SUMMARY OF THE INVENTION

The present invention provides a riser drilling system including at least one gimbal joint and preferably a plurality of them spaced along the riser to even out deflection. The gimbal joint of the invention includes load cell means for controlling the gimbal joint deflection. The gimbal joint primary load transmission does not involve the primary sealing surfaces thereof. When a plurality of such gimbal joints are axially spaced in a riser, a curved beam is simulated by allowing relative angular movement between the casing joints without causing or depending upon flexure of the casing. When the riser system is maintained in tension from support at the platform, the deflection force provided by the load cell means at the gimbal joints tends to correct reversal of pipe angle, i.e. "snaking" (the situation depicted in the U.S. patent of McNiel 2,606,003).

One of the gimbal joints is preferably located just above the blowout preventer near the ocean floor. A telescoping joint to provide for vertical motion of the platform is preferably included in the system when the platform is a floating or mobile one.

Objects of the invention thus include providing for lateral movement of the drilling platform while minimizing excessive wear and side loading; and, while facilitating retention of control, allowing circulation of mud, fluids and cuttings, and guidance for running, connection and disconnection of wellhead parts, tools and conduits.

The principles of the invention will be further herein-after discussed with reference to the drawings wherein a preferred embodiment is shown. The specifics illustrated in the drawings are intended to exemplify, rather than limit, aspects of the invention as defined in the claims. Specifically, it should be borne in mind that the gimbal system disclosed could be advantageously used in other environments, for instance chemical process plant fluid-tight piping systems, where pipe misalignments during transport of fluid under pressure must be dealt with.

In the drawings:

FIG. 1 is an overall elevation view of apparatus of the invention in operating position;
FIG. 2 is a fragmentary elevation view of part of the apparatus of FIG. 1 showing controlled deflection thereof and FIG. 2a is a view of a detail thereof on larger scale;
FIG. 3 is an elevation view, with one quadrant cut away and sectioned, of a controlled deflection gimbal joint according to the preferred embodiment of the invention; and
FIG. 4 is an exploded perspective view of the gimbal joint of FIG. 3.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A drilling system 10 is shown in FIG. 1 including a marine vessel 12 at the surface of a body of water 14 such as an ocean or gulf. The vessel 12 is provided with a well 16 through which drilling operations are conducted. The vessel also has anchor line provisions 18 for mooring the vessel on location. Other, similar vessels have drilling platforms cantilevered over the side of the vessel and/or have legs which may be lowered to the bottom to provide stable support. Other similar vessels are kept on location via automatic positioning systems which do not require mooring of the vessel. Any of these may be used in place of the vessel 12 shown. Once the drilling vessel has been properly located, drilling operations may begin. In the typical operation shown already underway in the drawing, a template or landing mat 20 loaded with ballast has been lowered to support on the ocean floor 22. A drill string having an appropriate lowering tool may be used to lower the mat 20. Guide lines (not shown) may lead from the mat 20 to the rig to assist in the lowering of the guide base or landing base.

The landing mat 20 has a central, vertical bore 24 provided at its upper extent with a coaxial, annular, upwardly concave, spherically curved seat 26. A hole is then drilled down through the template into the ocean bottom for installation of the conductor pipe. At this stage, no environment-excluding conduit need extend to the surface. Water may be pumped down through the drill string to assist in washing material from the
hole being drilled, with returns spilling out at the ocean floor.

A guide base or landing base 28 is next secured around the guidelines leading down to the landing mat using a guide frame (not shown) and lowered to support on the landing mat, for instance on a drill string. Once the guide base has landed, the guidelines leading from the landing mat may be retrieved.

The landing base 28 includes a short length of large diameter pipe 30 open at the lower end and topped by an integral, radially outwardly directed flange 32. A circular, radially outwardly extending frame 34 is secured to the pipe 30 intermediate its ends. A plurality, for instance four, guide posts 36 project upwardly from the frame 34 and include releasable connections for guidelines 38 which extend to the surface.

At its lower extent the frame 34 has a coaxial, annular downwardly convex, spherically curved seat 50, for instance provided by the lower edges of a plurality of equiangularly spaced, radiating, longitudinally extending plates 42. The seat 40 cooperates with the landing mat seat 26 in ball and socket fashion, mounting the landing base on the landing mat.

Some of the components subsequently lowered to the bottom or retrieved therefrom may be guided in transit by being provided with a conventional wraparound guide frame which runs along the guidelines 38. When use of the guide frame is completed it is unlatched and pulled free. During running and retrieving, the guidelines 38 are maintained under tension, for instance by their being secured to conventional constant tension winch arrangements 44 mounted in the vessel well 16 below the rotary table 46.

In order to accommodate the landing base 28 to the particular type of end connections shown in the drawing, an axial short cross-over sub 48 is shown secured on the upper end of the landing base. The sub 48 has a radial flange 50 at its lower ends, by which it is bolted at 52 to flange 32. At its upper end, the sub 48 is provided with an enlarged flange 54, having an annular, external frustoconical clamp receiving wedging surface 56; an annular, internal, inwardly flaring frustoconical sealing surface 58 and an axially presented upper end surface. (A similar flange is described in greater detail in the U.S. patent of Watts et al. 2,766,999 in respect to FIG. 1 thereof.) When connection at 52, 50, 52 is performed at the surface, prior to lowering of the landing base 28. The sub 48 and connection at 32, 50, 52 may be wholly dispensed with by integrally providing the flange 54 directly on the upper end of the pipe 30.

If desired, the conductor pipe and first casing head may be run in a separate step, after the landing base, including its upper flange 54, have been landed. However, this requires the use of an additional remotely disconnectable connector to secure the first casing head to the landing base upper flange. As the first casing head remains in place, once landed, this would result in the permanent tying-up of a relatively expensive piece of equipment. Accordingly, the following alternative is preferred: prior to lowering of the landing base 28, a conductor housing or first casing head 60, with the conductor pipe 62 depending therefrom, is mounted on the landing base 28 at the landing base upper flange 54.

The casing head 60 is substantially the same as the casing head 100 shown in the U.S. Patent of Crain et al. 3,257,030, which describes the structure thereof in greater detail. First casing heads of other design could be used in the present instance. Suffice it to say, that the casing head 60 is generally tubular having a bore 64 communicating with the bore 66 of the conductor pipe 62 which depends from the lower end thereof. The upper end of the conductor pipe may be secured to the conductor housing or first hanger 68 in any suitable fashion, such as welding, threading or the like, as is common in the industry.

The bore of the first casing head 60 includes at least one casing hanger seat 68, and a hanger-to-head latching groove 70. The exterior of the first casing head 60, midway along the length thereof, is provided with an external circumferential rib 72, approximately equal in diameter to the O.D. of the flange 54. The rib 72 has a radially directed, axially facing lower surface 74 and a frustoconical axially facing, clamp wedging upper surface 76. As shown preassembled, the rib surface 74 abuts the flange 54 upper surface and an expansible-contraction clamp 78 holds the two secured together. The clamp 78 is of the type shown in FIGS. 9 and 10 of page 2105 of the Composite Catalog of Oil Field Equipment and Services; 1966-1967 edition; Gulf Publishing Co.; Houston, Tex., U.S.A.; and further described in the aforementioned U.S. Patent of Watts et al.

The head 60 extends generally cylindrical upwardly from the rib 72, terminating in an enlarged flange 80, which is similar to the flange 54, in that it includes an interior flared sealing surface, a flat end surface and an exterior flared clamp wedging surface. An enlarged, exterior cylindrical surface portion 81 on the head 60 just below its upper end acts as a guide for the remotely operable connector sliding piston, as will become more apparent hereinafter.

Once the guide base, conductor pipe, first casing head and hanger have been landed as a unit, for instance on a drill string, and the guide lines 38 connected, the conductor casing may be cemented in conventional fashion by forcing cement down the drill pipe, out through the lower end of the conductor pipe and up the annulus between the conductor pipe and the hole in the ocean floor.

In order that drilling of the remainder of the well may begin, the marine riser 82 is now installed. In general, the marine riser is made up at the surface, bottom to top, with appropriate checking of seats and seals, and installation of hydraulic, mechanical and other control lines completed in sequence as will be apparent to those familiar with underwater drilling.

With reference to FIGS. 1 and 2, the marine riser, from the bottom up, in the example shown, includes a first remotely connectable and disconnectable connector 84. The one shown is depicted and discussed in greater detail on page 2106 of the 1966-1967 edition of the Composite Catalog. Other remotely operable connectors could be used. Suffice it to say that, in the example shown, mechanical and/or hydraulic actuation of the piston 86 slides the clamp segments 88 radially into (shown) and out of (not shown) clamping engagement of the flanges 80 and 90. The flange 90 on the connector interiorly mounted a flexible lip seal ring 82, for instance as shown in FIGS. 1 and 4–6 of the U.S. patent of Watts et al., 3,231,297.

A conventional blowout preventer stack is shown, somewhat schematically, at 94.

Although requirements vary depending upon pressures expected to be encountered and drilling and completion procedures to be followed, a typical blowout preventer stack might include one or more ram-type preventers 96 provided with pipe and blind rams, surmounted by a bag type preventer 98. The stack may be an integrated structure including supporting and guiding framework members and control line connections. The stack 94 shown includes upper and lower tubular sections 102, 100, terminating in clamp and sealing ring receiver flanges 106, 104 which receive seal rings 110, 108 and clamps 112, for instance as in Watts et al. 2,766,999. The clamp 112 mounts the stack 94 on the remotely disconnectable connector 84; the clamp 114 is shown mounting a tubular extension sub 116 on the stack tubular section 102. The extension sub 118 includes a clamp and sealing ring receiving flange 118 at its lower end, another one, 120, at its upper end and a piston guiding enlarged exterior cylindrical surface 122 intermediate its ends, similar to the surface 81 on the first casing head 60. The extension sub 116 could be made integral with the stack tubular.
section 102, thus eliminating the joint at 118, 114, 106, 110.

The remainder of the marine riser shown includes, from the bottom, a second remotely operable connector 124, a first gimbal joint 126 constructed in accordance with the present invention and depicted in greater detail in FIGS. 3 and 4, a long segment 128 of marine riser conduit, consisting for instance of several joints thereof, a second novel gimbal joint 130, a second long segment 132 of marine riser conduit, a third novel gimbal joint 134, and the remaining segment 136 of the conventional vertical motion permitting, telescoping joint 138 and a bell nipple 140 at the upper end thereof with connection provisions 142 at the vessel well for retaining a constant tension on the marine riser.

The novel gimbal joints 126, 130 and 134 will now be described in greater detail with reference to FIGS. 3 and 4. Since the joints 126, 130 and 134 are alike, the joint 126 will be used as an example.

The gimbal joint 126 includes a centrally located, tubular gimbal seal mounting ring 142, shown having its thickest section midway along the axial length thereof. A circumferential rib 144 is formed on the ring 142, exteriorly thereof, at the thickest section. From this section the ring thickness gradually decreases in both axial directions, both interiorly and exteriorly. Accordingly, when the gimbal seal ring 142 sits during use, to the permitted degree of axial effectiveness of its through bore 143 remains substantially the same, minimizing any tendency for equipment to hang or bind within the gimbal seal ring through bore.

Anular seal rings 146, 148 of resilient long wearing sealant resistant to seawater, etc., are recessed in the radially inner corners of the ends of the gimbal seal ring 142 so as to extend slightly axially beyond (for instance, 3/8 inch beyond) flushness with the adjacent radially outer corners of the gimbal seal ring. The gimbal seal ring outer corner axial end surfaces and annular sealing rings 146, 148 axial outer end surfaces are spherically, convexly curved about a point P lying at the geometric center of the gimbal seal ring 142. Thus, the gimbal seal ring outer corner axial end surfaces engage the seats 168 to transmit some of the load between these members, causing the trunnions 192 to be loaded as simple beams instead of as cantilever beams. The load carried by the gimbal seal ring 142 does not cause vertical movement of the ring due to transfer of the load to the opposing two trunnions, and because of its low magnitude, the load on the gimbal seal ring does not distort the gimbal seal ring.

A spaced annular seal interface 150 is provided about the ring 142, radially outwardly opening cylindrical sockets 150, 152, 154, 156 are formed therein through the rib 144, but terminating short of the bore 143. The longitudinal axes of these sockets intersect at the geometric center P of the gimbal seal ring 142.

The gimbal joint 126 further includes two end connector elements 158, 160 which are substantially identical in structure, excepting that the upper one, 160, is inverted and rotated 90 degrees about the longitudinal axis thereof, from the lower one, 158, in assembling the gimbal joint 126. The lower end connector element will be further described by way of example.

The lower end connector element 158 is generally tubular having an exterior which gently flares toward the flat, axially facing, axially inner end thereof 161. The axially outer end of the element 158 is provided with means for securing it to an aligned conduit end, for instance the end of a marine riser, a pipe end, etc., and then the connection is to be made using contractile-expansible clamps as described in the aforementioned Watts et al. U.S. patent 2,766,999, the securing means on the element 158 lower end may comprise a flange 162 provided with an exterior clamp wedging surface 164 as shown.

Toward its outer end, the through bore 166 of the element 158 is generally cylindrical, merging axially inwardly with a coaxial, annular, spherically, convexly curved seat 168 which flares toward the end 161. The seat surface 168 is curved about the point P and has a radius, from the point P (when assembled, FIG. 4), that is, slightly greater than that of the gimbal seal ring outer corner axial end surfaces and slightly smaller than that of the gimbal seal ring 142 sealing rings 146, 148 axially outer end surfaces. Its length of arc, in the sense parallel to the longitudinal axis of the element 158 is about 30%. The element 158 is provided with an exterior clamp 170, 172 shown secured, for instance by welding, to diametrically opposed regions on the exterior of the element 158 and extending axially beyond the inner end 160 thereof. The ears 170, 172 could be integrally formed on the element 158. Aligned cylindrical holes 174, 176 are formed through the ears 170, 172 along a diametrical line which passes through the point P.

The direct distance between the facing inner surfaces of the two ears 170, 172 is at least slightly greater than the outer diameter of the gimbal seal ring rib 144 in order to prevent interference during operation of the gimbal joint.

The gimbal joint 126 further includes a gimbal ring or trunnion mount ring 178 which, in the example shown, is generally tubular and of approximately the same axial diameter as the effective length of the gimbal seal ring. The trunnion mount ring 178 has an inner diameter which is larger than the direct diametral distance between corresponding points on the exterior of the four ears 170, 172.

At four equiangularly spaced joints radially directed openings 180, 182, 184 and 186 are formed centrally therethrough on radii which intersect at the point P. Peripherally adjacent the openings 180-186, flats 188 are formed on the exterior of the trunnion support ring 178. A plurality of small threaded openings 190, for instance three, are shown surrounding each opening 180-186, opening through respective flats 188.

In assembling the gimbal joint, the gimbal seal ring 142 is placed on the lower end connector element 158 sealing surface 168 so that the gimbal seal ring sockets 150 and 154 are axially aligned with the openings 174, 176 through the ears 170, 172 of the lower end connector element.

The upper end connector element 158, inverted and in the orientation shown in FIG. 3 is lowered onto the gimbal seal ring so that the gimbal seal ring sockets 152 and 156 are axially aligned with the openings 174, 176 through the ears 170, 172 of the upper end connector element and the axially upper end of the gimbal seal ring engages the upper end connector seat 168. The gimbal ring or trunnion mount ring 178 is lowered to a girth encircling position respecting the subassembly just described. The openings 180, 182, 184, 186 of the gimbal ring or trunnion mount ring 178 are respectively axially aligned with the gimbal seal ring sockets 150, 152, 154, 156.

The gimbal joint 126 further comprises four gimbal pins or trunnions 192, each comprising a generally cylindrical axle portion 194 and a mounting means 196 shown comprising a threaded socket in the outer end of the axle portion, a circular plate 198 having a central and several angularly spaced radially intermediate openings 199 therethrough. A bolt 200 received through the central opening and threaded into the axle portion socket secures the plate to the axle portion. The gimbal pin inner ends are inserted through respective openings 180, 182, 184, 186 and then through respective openings 174, 176 of the upper and lower end connector elements, and into the respective sockets 150, 152, 154, 156. Bolts 202 are then threaded through the openings 199 into the threaded openings 190 on the trunnion support ring. This secures the trunnions or gimbal pins to the trunnion mount ring or gimbal ring; journals the upper end connector.
element for pivotal movement with respect to the trunnion mount ring about the axis of the two trunnions which support it; journals the trunnion mount ring for pivotal movement with respect to the lower end connector element about the axis of the two trunnions connecting these elements; and supports the gimbal seal ring 142 within the joint in sealing engagement with the upper and lower end connector element spherically curved sealing surfaces 168.

A particularly important feature of the gimbal joint 126 will now be described. It should be apparent that, were the gimbal joint 126 to consist only of the parts so far described, it would have no means to maintain a condition wherein the upper and lower end connector elements are axially aligned. Furthermore, if deflected from axial alignment, little or no restorative force would be present to return the joint to an axially aligned condition. In addition, if several of such joints were interspersed in a marine riser pipe, the pipe could assume a snaked condition wherein each of the joints was bent toward a different azimuth.

In underwater well drilling, this state of affairs would be highly undesirable, since well drilling or completion parts disposed within the riser could become stuck therein, tubular parts could hang and twist off and, in any event, excessive wear of the parts and of the riser could be expected.

In order to prevent such undesirable occurrences, the gimbal joint of the invention is provided with means tending to predispose it in an angularly aligned condition and tending to restore it to an angularly aligned condition, if deflected therefrom.

In the embodiment shown, these predisposing and restoring means comprise a plurality of load cells 204, 206 respectively mounted between the lower end connector element and the gimbal ring, and between the upper end connector element and the gimbal ring. Although arrangement modifications are possible, the presently preferred embodiment provides two load cells 204 diametrically opposite one another midway between the ears 170, 172 of the lower end connector and two load cells 206 diametrically opposite one another midway between the ears 170, 172 of the upper end connector.

The load cells 204 and 206 are all of substantially identical construction and may, for instance, comprise a double-acting steel coil spring 208 having a force constant of 6,000 to 7,200 pounds per foot, and an unstressed length of about 10 inches. Each spring is received within a capsule consisting of opposed cup-shaped sections 210, 212. The capsule section 210 is of smaller O.D. than the I.D. of the section 212 and the former is partly received within the latter. The ends of the spring are fixedly mounted in the respective sections 210, 212. A U-shaped annular, flexible rubber diaphragm having opposite ends thereof sealingly connected to the facing, overlapping surfaces of the sections 210 and 212 excludes the marine environment from the spring. Suitable means, such as eyes 214 on the section 210, 212 outer ends, the gimbal ring, and the upper and lower end connector elements, together with nut and bolt assemblies 216 through the eyes, mount the load cells on the gimbal joint.

In the construction shown, the load cells extend between the exterior of the respective end connector elements and the nearest axial ends of the gimbal ring, forming approximately 30 degree angles with the longitudinal axis of the gimbal joint, when the gimbal joint is in an axially aligned condition.

Upon angular tilting of the gimbal ring about the trunnions pinning it to the gimbal ring one of the load cells 206 will be compressed and the other will be extended under tension. The restorative force provided by both loads in a sense to return to an unstressed condition will tend to return the gimbal ring to the datum position shown in FIG. 4.

Upon angular tilting of the upper end connector element about the trunnions pinning it to the gimbal ring one of the load cells 206 will be compressed and the other will be extended under tension. For the joint as a whole, the restorative force is substantially proportional to the degree of tilt of the upper end element with respect to the lower end element, irrespective of the azimuth.

It should be apparent that more similar load cells could be provided, angularly spaced about the joint. Also, it should be apparent that the load cells need not comprise a coil spring or an encapsulated coil spring, but could, for instance, comprise hydraulic pneumatic and/or mechanical equivalent thereof. An example of a commercially available device which could be used as load cells 204 and 206 is a compression loaded liquid spring available from Taylor Devices, Inc., New York, or as shown in the U.S. patent of Taylor, 3,256,005.

The load cells need not be of a type having a zero restorative force null position from which they can be disturbed by extension or compression of the restorative force providing element. In fact, in some applications, such a device would be undesirable since it would be relatively "dead" at and near its null position. Instead, the load cells may be provided with pretensioned or pre-compressed restorative force providing elements, respective ones of which counterbalance one another about the joint.

As another alternative one or more precompressed load cells may be fixedly mounted, via one end, on either the trunnion mount ring 178 or an end connector element 158 or 159 having its free end positioned to bear against the adjacent element 178, 158 or 160 to which it is not attached. Thus such load cells operate in compression only, since the adjacent element, if displaced further, merely moves free of the particular load cell free end after the load cell has recovered to its datum position.

In the embodiment shown, the maximum possible tilt of the upper end connector element with respect to the lower end connector element is about four degrees, at which point the axial end surfaces of the rib 144, of the seal mounting ring 142, contacts the exterior face 161 of the end connector element 158. Such contact does not cause any load to be transmitted to the seal ring seat surface 168 or the seal ring seats 146, 148. As it is, within the allowed degree of tilting or at maximum deflection, the seals 146, 148 are always in annular, resilient sealing contact with the sealing surface 168 regardless of the degree of azimuth of allowed tilting. Furthermore, it should be apparent that when the joint 126 is incorporated in a string of heavy pipe, the weight of the portion of the string which is above the joint and the effect of any tensile strain pulled on the string from above, substantially bypass the seals at 146, 168 and 148, 168 and are transmitted between the two end connector elements via the gimbal ring, trunnions and seal ring 142 without any relative movement to cause the seal ring 142 to engage the spherical seats 168.

Another feature of the joint 126 is worthy of note; inasmuch as the seals at 146, 148 are at all times circumferentially surrounded by an outer portion of the respective end connector element adjacent its end 160, fluid pressure within the joint tends to push the seals into tighter sealing contact with the seats 168. Thus, the embodiment shown in FIG. 4, when in use in an underwater drilling system is enabled to withstand an external pressure of at least about 200–300 p.s.i. However, apparatus constructed in accordance with the principles of the invention may be used in industrial applications in process equipment under nearly static conditions feasibly reaching several thousand pounds per square inch of pressure.

Returning to FIGS. 1, and 2, axially spaced incorporation of several, for instance three, of the novel gimbal joints in the marine riser at for instance 40 to 80 foot intervals preferably starting immediately above the preventer stack spaced the necessary angular deflection out
over the length of the riser and maintains the diameter of the bore of the riser, minimizing chances that well drilling or completion parts will hang or become stuck in a bend. Furthermore, since the load cells of all of the novel gimbal joints may be provided with equal restoring forces, if desired, the longer moment arm to which the lowest gimbal joint is subject will cause full deflection therefore the next upper gimbal joint deflections, etc. up to the uppermost joint. Deflection is thus controlled and snaking prevented.

Once the riser has been installed as described, further well drilling and completion operations may be conducted through the riser, for instance as more completely described in the abovementioned Crain et al. U.S. Pat. 3,287,030 and/or as described in the U.S. patents of Hepp of 2,368,315 and 3,366,978. This may include lowering a drill string down through the riser bore, drilling hole for the next inner casing string 220, and lowering the casing string 220 with its hanger 222 to support within the casing head 60. (The particular hanger 222 shown in FIG. 1 is shown in more detail in the abovementioned Crain et al. U.S. pat.)

If during drilling and/or completion it should for some reason become necessary or desirable to separate the marine riser and remove or replace segments thereof, this may be done by manipulation of the remotely disconnectable connectors, described above. For instance, although one set of blowout preventers may be used throughout the drilling and completion of the well shown in FIG. 1, some operators may wish to initially use a large bore, lower pressure rated unit, then switch to a smaller bore, higher pressure rated unit when drilling hole for the oil string of casing.

Once drilling is finished the well may be completed, or temporarily or permanently abandoned as is known in the art. At such stage, the marine riser, including the blowout preventers, is detached from the well and retrieved for reuse.

The novel gimbal joints described herein, except for the resilient seal rings described above, are preferably made of AISI 4140 steel. If needed for corrosion or environmental protection, working surfaces of the gimbal joints may be coated with standard protective coatings, such as electroless nickel coatings.

More or less than three of the novel gimbal joints could be advantageously used in the riser, and in instances where only one is employed, for instance just above the BOP stack, inclusion of the load cells on the joint is not essential in some instances, as will be apparent.

It should now be apparent that the riser drilling system with controlled deflection gimbal joints as described hereinabove possesses each of the attributes set forth in the specification, particularly “Summary of the Invention” hereinabove. Because the riser drilling system with controlled deflection gimbal joints of the invention can be modified to some extent without departing from the principles of the invention as they have been outlined and explained in this specification, the present invention should be understood as encompassing all such modifications as are within the spirit and scope of the following claims.

What is claimed is:

1. In a tubular joint having two axially alignable pivotally interconnected tubular conduit elements and including means sealingly interconnecting the through bores of the two tubular conduit elements, the improvement comprising: a support member positioned adjacent the pivotal interconnection of the tubular conduit elements; at least one first load cell having an end thereof secured to one of the tubular conduit elements and an opposite end thereof connected to the support member; at least one second load cell having an end thereof secured to the other of the tubular conduit elements and an opposite end thereof connected to the support member; each load cell including means for exerting an axial alignment restoring force between the support member and the respective tubular conduit element in proportion to the deflection of the respective tubular conduit element from axial alignment with the support member.

2. A gimbal joint for a fluid conduit comprising: a first tubular element having a longitudinal through bore; a second tubular element having a longitudinal through bore; means defining an annular, coaxial, concave, spherically curved sealing surface on each of said tubular elements, within the through bore thereof, adjacent and enlarging toward one end of respective tubular elements; a gimbal ring disposed circumferentially of said joint adjacent said tubular element one ends; first gimbal pin means on said gimbal ring, proceeding radially thereof from two diametrically opposed locations on said gimbal ring; said first gimbal pin means pivoting mounted said first tubular element at two diametrically opposed locations on said first tubular element; second diametrically opposed gimbal pin means on said gimbal ring, disposed angularly intermediate said first gimbal pin means; said second gimbal pin means pivotally mounting said second tubular element at two diametrically opposed locations on said second tubular element; and a tubular sealing ring having a through bore and first and second axial ends; means defining a coaxial, annular sealing surface on each end of said sealing ring; said sealing ring being received within said joint with said first axial and coaxial, annular sealing surface in sealing engagement with the annular, coaxial, concave, spherically curved sealing surface of said first tubular element, with said second axial end coaxial, annular sealing surface in sealing engagement with the annular, coaxial, concave, spherically curved sealing surface of said second tubular element, with said through bore thereof communicating between the through bores of said first and second tubular elements, and with longitudinal axes of said first and second gimbal pin means passing through the geometric center of said sealing ring.

3. The gimbal joint of claim 2 wherein said sealing ring, at least at the first and second axial ends thereof, is made of resilient material, said sealing ring having a free axial length between said sealing surfaces thereof greater than the direct distance between corresponding points on said sealing surfaces of said tubular elements engaged by the sealing ring sealing surfaces, whereby said sealing ring sealing surfaces resiliently engage said sealing surfaces of said tubular elements.

4. The gimbal joint of claim 2, wherein the two tubular elements each includes two diametrically opposed ears extending axially beyond said one end of each; each ear having means defining an opening therethrough radially of the respective tubular element, all on axes passing through the geometric center of the sealing ring; means defining four equiangularly spaced, radially outwardly opening sockets in said sealing ring, all on axes passing through the geometric center of the sealing ring; said gimbal ring circumferentially surrounding all of said ears; said first gimbal pin means passing radially inwardly through respective of the openings through the two ears of the first tubular element and into two diametrically opposed ones of the sockets on said sealing ring; said second gimbal pin means passing radially inwardly through respective of the openings through the two ears of the second tubular element and into the remaining two diametrically opposed ones of the sockets on said sealing ring.

5. The gimbal joint of claim 4 wherein said sealing ring through bore, centrally thereof, is at least as large in diameter as the through bores of said first and second tubular elements; said sealing ring through bore enlarging in diameter from centrally thereof toward both axial ends thereof, whereby a fully open bore is maintained thereit although said sealing ring through bore, centrally thereof, is at least as large in diameter as the through bores of said first and second tubular elements.

6. The gimbal joint of claim 4 further including two load cells secured, at one end of each, to diametrically opposed points on said first tubular element angularly intermediate the two ears theoreon and secured, at an opposite end of each, to diametrically opposed points on...
said gimbal ring; and two load cells secured, at one end of each, to diametrically opposed points on said second tubular element angularly intermediate the two ears thereon and secured, at an opposite end of each, to diametrically opposed points on said gimbal ring; each said load cell comprising a resiliently compressible-expanisible member means constructed and arranged to offer a restorative force proportional to the displacement of said member from said unstressed condition, whereby said gimbal joint is predisposed to maintain an axially aligned condition.

7. The gimbal joint of claim 6, further including: a gimbal ring; and two load cells secured, at one end of each, to diametrically opposed points on said second tubular element; second diametrically opposed gimbal pin means on said second tubular element; and said gimbal joint comprising a resiliently compressible member means constructed and arranged to offer a restorative force proportional to the compression of said member from said unstressed condition, whereby said gimbal joint is predisposed to maintain an axially aligned condition between said first tubular element and said gimbal ring.

9. The gimbal joint of claim 8, further including at least one load cell secured at one end thereof to one of said second tubular elements, angularly intermediate the two ears thereon and said gimbal ring; and having the opposite end thereof positioned to bear against the other of said second tubular element, angularly intermediate the two ears thereon and said gimbal ring; said load cell comprising a resiliently compressible member means constructed and arranged to offer a restorative force proportional to the compression of said member from said unstressed condition, whereby said gimbal joint is predisposed to maintain an axially aligned condition between said second tubular element and said gimbal ring.

10. A marine riser for providing, during an intermediate stage of well drilling, communication between a drilling vessel and well control equipment at an underwater wellhead comprising: a string of conduit having connector means at the lower end thereof constructed and arranged to secure said string of conduit to said well control equipment, and having support means at the upper end thereof for connection to the drilling vessel for supporting at least part of the weight of the string of conduit from the drilling vessel; said connector means disposed in said string of conduit adjacent said connector means, said gimbal joint comprising: a first tubular element having a longitudinal through bore; a second tubular element having a longitudinal through bore; means defining an annular, coaxial, concave, spherically curved sealing surface on each of said first and second tubular elements, with said bore thereof, adjacent and enlarging toward one end of respective tubular elements; a gimbal ring disposed circumferentially of said joint adjacent said tubular element one ends; first gimbal pin means on said gimbal ring, proceeding radially thereof from two diametrically opposed locations on said gimbal ring; said first gimbal pin means pivotally mounting said second tubular element at two diametrically opposed locations on said second tubular element; and said gimbal joint comprising: a first gimbal pin means on said gimbal ring, disposed angularly intermediate said first gimbal pin means; said second gimbal pin means pivotally mounting said second tubular element at two diametrically opposed locations on said second tubular element; and a tubular sealing ring having a through bore and first and second axial ends; means defining a coaxial, annular sealing surface on each end of said sealing ring; said sealing ring being received within said joint with said first axial end coaxial, annular sealing surface in sealing engagement with the annular, coaxial, concave, spherically curved sealing surface of said first tubular element, with said second axial end coaxial, annular sealing surface in sealing engagement with the annular, coaxial, concave, spherically curved sealing surface of said second tubular element, with said through bore thereof communicating between the through bores of said first and second tubular elements, and with longitudinal axes of said first and second gimbal pin means passing through the geometric center of said sealing ring; said first and second tubular elements constituting part of said string of conduit.

11. A marine riser for providing, during an intermediate stage of well drilling, communication between a drilling vessel and well control equipment at an underwater wellhead comprising: a string of conduit having connector means at the lower end thereof constructed and arranged to secure said string of conduit to said well control equipment, and having support means at the upper end thereof for connection to the drilling vessel for supporting at least part of the weight of the string of conduit from the drilling vessel; and a plurality of longitudinally spaced gimbal joints interposed in said string of conduit at longitudinally spaced locations therealong, including: a first gimbal joint comprising: a first tubular element having a longitudinal through bore; means defining an annular, coaxial, concave, spherically curved sealing surface on each of said tubular elements, with said through bore thereof, adjacent and enlarging toward one end of respective tubular elements; a gimbal ring disposed circumferentially of said joint adjacent said tubular element one ends; first gimbal pin means on said gimbal ring, proceeding radially thereof from two diametrically opposed locations on said gimbal ring; said first gimbal pin means pivotally mounting said first tubular element at two diametrically opposed locations on said first tubular element; said second gimbal pin means on said gimbal ring, disposed angularly intermediate said first gimbal pin means; said second gimbal pin means pivotally mounting said second tubular element at two diametrically opposed locations on said second tubular element; and said gimbal joint comprising: a first gimbal pin means on said gimbal ring, disposed angularly intermediate said first gimbal pin means; said second gimbal pin means pivotally mounting said second tubular element at two diametrically opposed locations on said second tubular element; and a tubular sealing ring having a through bore and first and second axial ends; means defining a coaxial, annular sealing surface on each end of said sealing ring; said sealing ring being received within said joint with said first axial end coaxial, annular sealing surface in sealing engagement with the annular, coaxial, concave, spherically curved sealing surface of said first tubular element, with said second axial end coaxial, annular sealing surface in sealing engagement with the annular, coaxial, concave, spherically curved sealing surface of said second tubular element, with said through bore thereof communicating between the through bores of said first and second tubular elements, and with longitudinal axes of said first and second gimbal pin means passing through the geometric center of said sealing ring; said first and second tubular elements constituting part of said string of conduit.
ring; said gimbal ring circumferentially surrounding all of said ears; said first gimbal pin means passing radially inwardly through respective of the openings through the two ears of the first tubular element and into two diametrically opposed ones of the sockets on said sealing ring; said second gimbal pin means passing radially inwardly through respective of the openings through the two ears of the second tubular element and into the remaining two diametrically opposed ones of the sockets on said sealing ring; and each gimbal joint further including: two load cells secured, at one end of each, to diametrically opposed points on said first tubular element angularly intermediate the two ears thereon and secured, at an opposite end of each, to diametrically opposed points on said gimbal ring; and two load cells secured, at one end of each, to diametrically opposed points on said second tubular element angularly intermediate the two ears thereon and secured, at an opposite end of each, to diametrically opposed points on said gimbal ring; each said load cell comprising a resiliently compressible-expansile member having an unstressed condition intermediate compressed and expanded extremes thereof and constructed and arranged to offer a restorative force proportional to the displacement of said member from said unstressed condition, whereby said gimbal joint is predisposed to maintain an axially aligned condition; the first and second tubular elements of each gimbal joint constituting part of said string of conduit.

12. The marine riser of claim 11 wherein all of the load cell resiliently compressible-expansile members have substantially equal force constants; and wherein the load cells of each gimbal joint are constructed and arranged to limit maximum longitudinal axis angular deflection of the first and second tubular elements thereof, with respect to one another, of about four degrees.

13. In a tubular joint having a first and a second axially alignable pivotally interconnected tubular conduit elements and including means sealingly interconnecting the through bores of the two tubular conduit elements, the improvement comprising: a support member positioned adjacent the pivotal interconnection of the tubular conduit elements; at least one load cell having an end thereof secured to one of the first tubular conduit element and support member and an opposite end thereof positioned to bear against the other of said first tubular conduit and said support member; said load cell including resiliently compressible means for exerting an axial alignment restoring force between the support member and the first tubular conduit element in proportion to the deflection of the first tubular conduit element from axial alignment with the support member.

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ERNEST R. PURSER, Primary Examiner
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