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(54) GUIDELINELESS SUBSEA WELLHEAD ENTRY OR RE-ENTRY SYSTEM

(71) We, FMC CORPORATION, a corporation organised and existing under the laws of the State of Delaware, United States of America, of 200 E. Randolph Drive, Chicago, Illinois, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

This invention relates to subsea wellhead systems, and more particularly to a guidelineless system for entry or re-entry into a subsea wellhead.

The production of oil and gas from offshore wells has developed into a major endeavour of the petroleum industry, and wells are commonly drilled several hunderd or even several thousand feet below the surface of the ocean. These wells must not only be drilled without the use of divers at the deeper depths, but the connecting, testing and servicing of pipes and of regulating valves must be performed on these wells during and after the drilling process.

Some wellhead facilities include a foundation casing which is connected to a wellhead guidebase and having a plurality of guideposts connected to the guidebase. A separate guide cable is connected between each of the guideposts and a surface vessel so that the subsea tree, blowout preventers, valves and service tools can be guided into position on the well by these guide cables. If these guide cables break or become entangled it is expensive to correct the problem and to lower the equipment to the wellhead. If the well should be temporarily abandoned it is necessary to remove the cables from the guideposts so that the cables can be retrieved. If it is desired to reenter the well at a later time it is necessary to send divers to the seafloor to connect new cables to the guideposts. In deeper water this is impossible to do; and even in shallower water this procedure is expensive.

Some wellhead facilities include guidelineless apparatus having TV/sonar guidance equipment which uses TV and sonar for visual guidance of working tools into position to remove the tree assembly from the seafloor and raise the tree assembly to a surface vessel for repair and service. This equipment does not have the accuracy and dexterity of movement required for much of the repair work on the equipment at the seafloor. Therefore, the tree assembly must be removed and brought to the surface for some of the repair work, a procedure which is time consuming and expensive.

There is a requirement for apparatus which can be used to guide the service and repair equipment into precisely defined positions adjacent the wellhead so that service work and repairs can be done on the tree assembly, valves, etc. without the time and expense of bringing these elements to the surface vessel.

According to the present invention there is provided a guidelineless subsea wellhead entry system for use with an elongated column and a subsea well having a subsea installation attached thereto, said system comprising an elongate probe connected to said column and a funnel having a mouth portion whose axis is offset relative to the axis of a smaller neck portion of the funnel, said funnel being connected to said subsea installation, means for locating said subsea installation, and means for moving said probe and said column toward said funnel.

The present invention also provides a guidelineless subsea wellhead entry system for use with a tubular column and a subsea well having a subsea installation attached thereto, said system comprising a locking probe connected to said tubular column, a funnel having a mouth portion whose axis is parallel to but spaced from the axis of a smaller neck portion of the funnel, said mouth portion having an internal surface which slopes to facilitate movement of said probe, upon entry into said mouth portion, toward said neck portion, said neck portion having means for securing said probe in position after said probe has beeen moved into said neck portion; means connecting said funnel to said subsea installation with the axis of said neck portion parallel to and spaced from the axis of the subsea well,

means for locating said subsea installation and a component manipulator device, said locating means and said manipulator device being connected to said tubular column.

The present invention further provides a guidelineless subsea wellhead re-entry system for use with a riser and a wellhead having a subsea tree attached thereto, said system comprising a locking probe, a funnel having a mouth portion whose axis is spaced from the axis of a smaller neck portion of the funnel and a surface sloping downwardly from the mouth portion to the neck portion, said funnel being connected to said subsea tree; means for connecting said probe to said riser; means on the probe for selectively locking said probe in said neck portion of said funnel when said probe is properly positioned in said neck portion, a component manipulator device for connecting and disconnecting components from said subsea tree, signal sending and receiving means, means for connecting said manipulator device and said signal means to said riser, and signal reflecting means mounted on said subsea tree.

The present invention further provides a guidelineless subsea wellhead entry system for use with an elongated column and a subsea well having a subsea installation attached thereto, said system comprising an elongated probe, a funnel having a mouth portion and a smaller neck portion, the axis of said neck portion being parallel to and spaced from the axis of said mouth portion of said funnel, one of said probe and funnel being connected to said subsea installation, the other being connected to said column, means for locating said subsea installation and means for moving said probe and said column relatively toward one another.

The word 'column' as used above and in the claims appended hereto is intended to include a riser, a drill pipe or a flexible cable.

The invention will now be particularly described by way of example, with reference to the accompanying drawings in which:–

Figure 1 is a perspective view of a guidelineless subsea wellhead system according to the present invention, illustrating the reentry apparatus;

Figure 2 is a front elevation of a portion of the guidelineless system of Figure 1 showing details of the reentry apparatus;

Figure 3 is a side elevation of the reentry apparatus shown in Figure 2;

Figure 4 is a plan of the apparatus of Figure 3, viewed in the direction of the arrows 4-4 of Figure 3;

Figure 5 is a side elevation of the reentry funnel and locking probe;

Figure 6 is an enlarged isometric view of a portion of the funnel of Figure 5;

Figure 7 is a plan of the apparatus of Figure 5, viewed in the direction of the arrows 7-7 of Figure 5;

Figure 8 is a side elevation, similar to Figure 5, showing the probe locked into position in the funnel;

Figure 9 is a plan of the apparatus of Figure 8, viewed in the direction of the arrows 9-9 of Figure 8;

Figures 10-13 are side elevations, similar to Figure 8, showing a sequence of operation of the apparatus;

Figure 14 is a plan of the apparatus of Figure 12, viewed in the direction of the arrows 14-14 of Figure 12;

Figure 15 is a plan of the apparatus of Figure 13, viewed in the direction of the arrows 15-15 of Figure 13;

Figures 16 and 17 are side elevations, similar to Figures 10-13, showing a further sequence of operation of the apparatus;

Figure 18 is a horizontal section taken along line 18-18 of Figure 10;

Figure 19 is a developed view taken generally in the direction of arrows 19-19 of Figure 18;

Figure 20 is a plan view, similar to Figure 14 but with a portion of the apparatus removed to show placement of other portions;

Figure 21 is a horizontal section, similar to Figure 18, of a second embodiment of the invention;

Figure 22 is a developed view taken generally in the direction of arrows 22-22 of Figure 21;

Figure 23 is an enlarged side elevation with portions being broken away, of a tree cap for a wellhead;

Figure 24 is an enlarged side elevation with portions being broken away, of the running tool;

Figure 25 is a side elevation of a second embodiment of the locking probe;

Figures 26-37 disclose a sequence of operation of a subsea wellhead system using the present invention for both entry and reentry of subsea well.

A guidelineless subsea wellhead re-entry system in accordance with the first embodiment comprises a completion riser 11 or other type of tubular column having the upper end thereof connected to a surface vessel 12 (Fig. 1) and the lower end thereof connected to a component manipulator device 15. Connected between the vessel 12 and the lower end of the manipulator device 15 is a TV/sonar tool 16 which is used to locate a subsea installation, such as a wellhead 17. The TV/sonar tool is encased in the riser 11 with the upper end thereof connected to standard TV/sonar sending/receiving equipment (not shown) inside the vessel, and with the lower end of the tool 16 projecting below the end of the riser 11. The TV/sonar tool may be one of the types

which is commercially available, such as the "High Resolution Reentry (HRR) System" manufactured by the Edo Western Corporation of Salt Lake City, Utah. Such a system includes a sonar transmitter which directs high frequency signals outward from the tool 16. These signals are reflected by reflectors, received by the tool 16, and directed to equipment aboard the surface vessel 12. Also connected to the lower end of the manipulator device 15 is a reentry probe 20 which is adapted to slide into operating position in an offset reentry funnel 21 located on the upper portion of the wellhead. The wellhead 17 includes a guidebase 23 that is connected to a foundation casing (not shown) which extends into a seafloor 25. Mounted on the guidebase 23 are a plurality of support posts 24, a subsea tree 29 and a plurality of guide posts 30. Mounted on the upper ends of the support posts 24 is a support plate 27 which supports the upper end of the subsea tree 29. Connected to the offset funnel 21 are a plurality of sonar reflectors 26. A plurality of flowlines 31 (only one of which is shown) may be connected to the subsea tree 29. A tree cap 34 and a pair of control pods 35*a*, 35*b* are mounted to the upper end of the subsea tree 29. During the installation of the guidebase 23 it may be desirable to connect guide cables (not shown) to the guideposts 30 to aid in installing the subsea tree 29.

The component manipulator device 15 (Figs. 2-8) includes a pair of guide sleeves 36*a*, 36*b* connected between the riser 11 and the reentry probe 20. The left end of the upper guide sleeve 36*a* (Fig. 3) is free to pivot about the upper portion of the probe 20 while a riser guide spline 39, which is free to slide up and down in a groove 40 in the upper guide sleeve (Fig. 4), prevents the riser 11 from rotating relative to the right end of the guide sleeve 36*a*. An enlarged end portion 20*b* of the probe rests on the upper edge of the upper guide sleeve 36*a* to provide support for the probe 20. A replaceable tip 20*a* is connected to the lower end of the probe 20. The right end portion of the lower sleeve 36*b* is welded or otherwise fastened to the lower end of the riser to prevent the guide sleeve 36*b* from rotating relative to the riser 11. The left end portion of the lower guide sleeve 36b (Fig. 3) includes a bore having an inwardly projecting lug 42 which is free to slide up and down in a groove 44 in the probe 20.

A storage bracket 49 that is connected to the probe 20 includes a pair of storage depots 49*a*, 49*b* (Fig. 2) which are adapted to store tree caps or control pods. A spare tree cap 34*a* is shown in position on the storage depot 49*b* in Figures 3 and 4. The upper ends of a pair of hydraulic lowering rams 50*a*, 50*b* are connected to the upper guide sleeve 36*a* by a pair of ears 51 which are welded or otherwise connected to the sleeve 36*a*. The rams 50*a*, 50*b* may be powered in either an extending direction or in a collapsing direction. The lower end of each of the lowering rams 50*a*, 50*b* is connected to a running tool 54 by a pair of ears 55. The lowering rams are shown in the extended position in Figure 3 and with the lug 42 near the bottom of the groove 44. When the lowering rams are moved into the collapsed position shown in Figure 8 the upper and lower guide sleeves 36*a* and 36*b* are positioned adjacent each other. The running tool 54 is connected to the lower end of the riser 11. The lower end of the TV/sonar tool 16 is shown projecting below the running tool in Figure 3, but it should be understood that the TV/sonar tool may be retracted into the riser 11 when the running tool 54 is in use.

The tip 20*a* of the reentry probe 20 (Fig. 5) includes a guide key 58 and a plurality of probe latches 59. The reentry funnel (Figs. 5 and 6) includes an inwardly extending orienting cam 62 having a slot 63 and a plurality of funnel locking detents 64 near the bottom portion of the funnel. The funnel 21 is welded or otherwise connected to the upper portion 29*a* of the subsea tree 29 (Fig. 1). When the probe 20 is lowered into the funnel (Fig. 5) the tip 20*a* slides down the inclined portion 21*a* into the neck portion 21*b* where the key 58 of the probe makes contact with the orienting cam 62. As the probe is lowered further into the next portion of the funnel, the key 58 slides down the orienting cam 62 causing the probe 20 to rotate into the position shown in Figure 8 with the key 58 inside the slot 63 (Fig. 6), and the probe latches 59 projecting into the detents 64. The probe latches 59 and the detents 64 prevent the probe 20 from moving out of the funnel and allow the surface vessel to apply an upward tension on the riser to prevent it from buckling. The key 58 and the slot 63 orient the running tool 54 relative to the tree cap 34 and the control pods 35.

The reentry probe 20 includes a plurality of grooves 44, 67 and 68 (Figs. 3, 19) that cooperate with the inwardly projecting lug 42 to position the running tool 54 above one of the work or storage positions A, B, C shown in Figure 4. When the lug 42 is positioned in the lower portion of the groove 44, the riser 11 is in the "C position" as shown in Figures 3 and 4. As the probe 20 is moved downward, so that the lug 42 moves into a wider portion 44*a* of the center groove, the riser 11 is free to pivot about the probe 20 into a position a few degrees either side of the C position. This movement can best be seen by referring to Figures 17-19. The Figure 19 discloses a "developed view" of the probe 20 where the curved surface of

the cylindrical probe is drawn as a flat surface having the groove 44 in the center. The lower portion of the center groove 44 is substantially the same width as the lug 42 thereby preventing lateral movement of the lug in the lower portion of the groove 44. When the lug 42 moves into the wider portion 44a some lateral movement of the lug is possible. As the lug 42 moves upward to a position near a rotational stop 66, the lug 40 may move to the right (Fig. 17) in to the groove 67 or the left into the groove 68, thereby allowing the riser 11 to move into a "B position", shown in Figures 13 and 15, or into an "A position", shown in Figures 12 and 14.

After the probe 20 is locked into place in the funnel 21, the lug 42 may be biased to the right portion of the groove 44*a* by rotating the upper end of the riser 11 (Figs. 1, 11, 19) a few degrees in a counterclockwise direction as seen from the top of the riser. When the lug 42 reaches the top end of the groove 44 (Fig. 19) the lug then moves to the right against a right wall 66a so that the riser 11 and the running tool 54 are directly above the B position as shown in Figure 15. The lug can then be lowered into the groove 67 to enable the running tool 54 to pick up or to deposit a subsea tree component on the storage position B.

The lug 42 can then be raised to the top of the groove 67 (Fig. 19) by collapsing the hydraulic rams 50*a*, 50*b*, and the riser 11 can be rotated a few degrees clockwise to move the lug into a position against the right side of the rotational stop 66. When the hydraulic rams 50*a*, 50*b* are extended, the lug 42 moves down into the groove 44*a*. To move the lug into the groove 68 the riser 11 is biased a few more degrees clockwise and the hydraulic rams 50*a*, 50*b* are collapsed so that the lug 42 rides up the left side of the groove 44*a* and moves against a left wall 66*b*. The hydraulic rams 50*a*, 50*b* are then extended so that the lug 42 moves down into the groove 68 and the running tool 54 moves over the storage position A (Fig. 14). The position of the lug 42 in the grooves 44, 67 and 68, and the position of the running tool 54 relative to the positions A, B and C (Fig. 4), can be ascertained by knowing the rotational direction in which the riser 11 is biased while the hydraulic rams 50*a*, 50*b* are being collapsed or extended. The position of the running tool 54 can be doublechecked by extending the TV/sonar tool 16 (Fig. 3) from the lower end of the running tool and observing the wellhead area.

The tree cap 34 includes a generally cylindrical housing 45 (Fig. 23) having an annular top flange 46 at the upper end thereof and an annular lower flange 47 at the bottom end thereof. Spaced about the lower flange 47 is a plurality of threaded bores 48, only one of which is shown, extending vertically through the flange. Spaced about the lower end of the housing 45 is a plurality of guides 71, only one of which is shown in Figure 23, each guide having a threaded upper end, an enlarged cam surface 71*a*, and a cylindrically shaped lower portion having a threaded lower end portion. The upper end of each of the guides 71 is threaded into a corresponding one of the bores 48. An annular ring 72 is connected to the housing 45 by the guides 71. The lower portion of each of the guides extends through a bore 72*a* in the ring 72 and a nut 73 is threaded on to the lower end of the guide. An annular actuator ring 76 having a plurality of bores 76*a* therein is mounted above the ring 72 with each of the guides 71 extending through one of the bores in the actuator ring 76 so that the actuator ring 76 may move up and down about the guides 72. A plurality of locking dogs 77 are constructed of a split ring with the ring constructed so as to be biased in a radially outward direction to rest against the actuator ring 76. The locking dogs also rest on the upper edge of the annular ring 72. Mounted around the lower end of the housing 45 is a generally cylindrical shaped latching housing 79. The upper portion 79*a* of the latching housing 79 is slidably mounted about the outside of the housing 45. An annular groove 79*b* is provided near the upper end of the housing 79. An inner portion of the housing 79 is threaded at 79c to the outer portion of the actuator ring 76 so that the housing 79 and the actuator ring 76 move as a unit.

When the tree cap 34 (Fig. 23) is to be positioned on the upper end 29*b* (Fig. 11) of the subsea tree 29, the latching housing 79 and the actuating ring 76 (Fig. 23) are moved upward relative to the cylindrical housing 45 until the actuator ring 76 contacts the lower side of the lower flange 47. When the actuator ring 76 is moved upward away from the locking dogs 77 these dogs move outward against the guides 71 so that the tree cap 34 may be lowered onto the upper end 29b of the subsea tree 29 (Fig. 11). With the tree cap in position on the subsea tree, the latching housing 79 and the actuator ring 76 are moved downward into the position shown in Figure 23 so that the actuator ring 76 forces the locking dogs inwardly into the groove 32 formed in the end 29*b* (Fig. 11), thereby locking the tree cap securely onto the upper end of the subsea tree 29.

The running tool 54 includes a cylindrical housing 81 (Fig. 24) having an annular ring 82 threaded to the inside of the housing at the lower end thereof, and an annular adjustment ring 83 which is threaded to the lower inner surface of the cylindrical hous-

ing. An annular actuating piston 86 having an inwardly extending flange 86*a* at the upper end is slidably mounted inside the housing 81. The lower end of the actuating piston 86 includes a wedge-shaped cam surface 86*b*. A plurality of locking dogs 87 are constructed of a flexible ring which is biassed in a radially outward direction to rest against the lower portion of the actuating piston 86. The locking dogs 84 rest on the upper edge of the adjustment ring 83. An annular housing latching piston 88, having an outwardly extending flange 88*a* and an inwardly extending flange 88*b*, is slidably mounted inside the lower portion of the housing 81. Mounted inside the lower portion of the latching piston 88 is a split ring 90 which is biased in a radially outward direction against the latching piston 88. The split ring 90 rests against the upper edge of the flange 88b inside the lower end of the latching piston 88. An annular split ring-engaging piston 91 having a flange 91*a* on the upper end thereof is slidably mounted between the latching piston 88 and the lower portion of the adjustment ring 83. An annular retaining ring 92, which is connected to the latching piston 88 through slots 91*a* in the engaging piston 91, aids in retaining the split ring 90 in position adjacent the flange 88*b* of the piston 88. A ring 95 is threaded to an internal portion 96 of the housing 81. A secondary unlatching piston 97 is slidably mounted between the internal portion 96 of the housing and the actuating piston 86. A pipe 99 and a hydraulic line 100, which are mounted in the internal portion 96 of the housing, extend into the portion of the running tool where they may be connected to a pipe and a hydraulic line inside the subsea tree 29 of Figure 1.

Power to move the various pistons (Fig. 24) is supplied through a plurality of hydraulic lines 101a-101f. Power to raise the actuating piston 86 is provided by fluid which flows from the hydraulic line 101b into a chamber 103, thereby forcing fluid against the lower edge of the flange 86*a* and causing the piston 86 to move upward. Fluid supplied to a chamber 104 by a hydraulic line 101*c* provides a pressure to force the piston 86 in a downward direction. The actuating piston 86 may also be moved upward to release the locking dogs 87 by applying fluid under pressure to a chamber 105, thereby forcing the secondary unlatching piston 97 to move upward and to press against the flange 86*a* so that the piston 86 moves upward. This secondary unlatching piston is normally actuated only in the event that leakage of fluid or other failure in the hydraulic line 101b prevents the pressure in the chamber 103 from increasing enough to move the piston 86 to an unlatched position.

Power to raise the housing latching piston 88 (Fig. 24) is provided by hydraulic fluid which flows from the hydraulic line 101*e* into a chamber 108. The fluid in the chamber 108 provides an upward force against the flange 88a causing the piston 88 to move upward. The upper end of the piston 88 engages the flange 91a of the ring engaging piston 91 thereby moving the split ring engaging piston 91 into the position shown in Figure 24. Power to lower the latching piston 88 is provided by hydaulic fluid which flows from the hydraulic line 101f into chamber 109. The fluid in the chamber 109 provides a downward force on the upper surface of the flange 88a, thereby moving the piston 88 downwardly into position shown in Figure 24. Fluid also flows from the chamber 109 through a slot 110 in the piston 88 into a chamber 112 where the fluid provides an upward force on the flange 91a to move the ring engaging piston 91 to the position shown in Figure 24. Fluid from the hydraulic line 101d flows into a chamber 113, thereby providing a pressure which forces the ring engaging piston 91 in a downward direction. A plurality of seals 114 prevent hydraulic fluid from leaking from the chambers.

Operation

The sequence of operations used to pick up a tree cap 34 with the running tool 54, to place the tree cap on the upper end of a subsea tree 29, to lock the tree cap in position, and to remove the running tool from the tree cap will now be described in connection with the drawings of Figures 8, 11, 23 and 24. The sequence will start with the tree cap and the running tool elements in the positions shown in Figures 23 and 24.

In order to fit the running tool around the tree cap, the annular actuating piston 86 (Fig. 24) of the running tool 54 is moved to the upper end of the chamber 104 by applying hydraulic fluid to the chamber 103. This allows the locking dogs 87 to move against the inside surface 81a of the wall of the housing 81 so that the running tool 54 can be lowered on to the tree cap 34 (Figs. 8, 23) with the locking dogs 87 positioned adjacent the groove 46*a* (Fig. 23) and the split ring 90 adjacent the groove 79*b* of the tree cap. This position can be accurately determined because the locking dogs 87 will be adjacent the groove 46*a* when the ring 95 (Fig. 24) rests against the upper edge of the flange 46 (Fig. 23) of the tree cap. The adjustment ring 83 (Fig. 24) may be rotated to change the positions of the locking dogs 87 relative to the ring 95 and insure that the locking dogs are adjacent the groove 46*a*. This adjustment is made prior to fastening the running tool to the tree cap and lowering them to the seafloor.

When running tool 54 is in position

around the tree cap 34 hydraulic power is applied to the chamber 104 (Fig. 24), forcing the actuating piston downward and forcing the locking dogs 87 inwardly into the groove 46a (Fig. 23) of the tree cap 34, thereby locking the running tool securely to the tree cap housing. Hydraulic fluid is next applied to the chamber 113, causing the split ring energizing piston 91 to move downward and force the split ring 90 (Fig. 24) into the groove 79b (Fig. 23), thereby locking the split ring 90 (Fig. 24) and the latching piston 88 to the latching housing 79 of the tree cap.

The latching piston 88 and the slit ring 90 are then moved upward causing the actuating ring 76 to move upward, by applying fluid to the chamber 108, so that the locking dogs 77 of the tree cap (Fig. 23) move radially outward against the guides 71. When the locking dogs 77 are against the guides 71 the tree can can be moved onto the upper end 29*b* of the subsea tree 29 (Fig. 11) with the lower edge of the flange 47 of the tree cap (Fig. 23) resting on the upper edge of the flange 29*c* of the subsea tree (Fig. 11) and the locking dogs 77 adjacent the groove 32 of the subsea tree. The latching piston 88 of the running tool (Fig. 24) is then moved downward which forces the latching housing 79 of the tree cap (Fig. 23) and the actuator ring 76 down, thereby forcing the locking dogs 77 (Fig. 23) into the groove 32 (Fig. 11) and locking the tree cap 34 in place on the subsea tree 29.

The running tool can be released from the tree cap by moving the piston 91 (Fig. 24) upward to release the split ring from the groove 79b (Fig. 23), and by moving the piston 86 (Fig. 22) upward to release the locking dogs 87 from the groove 46a (Fig. 23).

In addition to locating and locking onto the wellhead, the present embodiment can be used to inspect the wellhead, remove a tree cap, replace a tree cap, remove a control pod, replace a control pod and undertake and complete downhole wireline operations with a single trip of the riser from the surface of the sea to the seafloor and return. For example, a tree cap can be removed, a new tree cap installed, and downhole work done, all in one trip to the seafloor. It is also possible to install guidelines, run TV, install flowlines and other tasks on this same trip. The steps of a tree cap replacement operation can be seen by observing the reentry sequence shown in Figures 1-16.

The component manipulator device 15 is first completely tested and serviced aboard the vessel 12 and a new tree cap 34*a* (Figs. 3 and 4) is locked onto the storage depot 49*b*. The surface vessel 12 (Fig. 1) is moved to within a few hundred feet of the wellhead 17 using the navigation system located on the vessel. The riser 11 and the component manipulator device 15 are lowered until the manipulator device is an area approximately 20 feet above the top of the tree cap 34. The TV/sonar tool is run through the bore of the riser 11 until the tool 16 protrudes from the bottom of the running tool 54 to a point flush with the lower tip 20a of the reentry probe 20. The TV/sonar tool is used for guidance while the tip 20a of the reentry probe is maneuvred to within six feet of the funnel 21 and directly above the mouth of the funnel. The riser 11 is rotated until the manipulator device 15 is within about 22.5 degrees of being aligned within its desired position relative to the funnel, i.e. with the probe guide key 58 (Fig. 5) being aligned with the slot 63 (Fig. 6) in the neck portion 21b of the funnel. It is possible to align the probe 20 with the funnel 21 prior to inserting the probe into the funnel so that rotation of the riser is not necessary.

The hydraulic lowering rams 50*a*, 50*b* are slowly powered down to lower the probe 20 into the funnel 21 (Fig. 5) so that the tip 20*a* of the probe slides along the inclinned portion 21*a* and into the neck portion 21*b* of the funnel (Fig. 8). The probe guide key 58 (Fig. 5) and the orienting cam 62 in the funnel (Fig. 6) cooperate to rotate the probe 20 and the riser 11 into the position shown in Figure 8 as stated hereinbefore. The probe latches 59, on the tip 20*a*, lock into the dentents 64 (Fig. 6) in the lower neck portion of the funnel. If mud or debris in the reentry funnel 21 should prevent proper entry of the probe into the funnel a stream of high pressure water can be directed through the riser 11 or through the probe 20 to clear such obstructions, and the probe is then moved into the funnel. The bottom end of the neck portion of the funnel 21 is open to facilitate cleaning such debris from the funnel.

Once the reentry probe 20 has been locked into place in the neck of the reentry funnel 21, a riser tensioning system (not shown) on the surface vessel 12 applies upward tension to the riser to assure safe operation and prevent collapse of the riser due to extreme bending of the riser. Such bending may be caused by movement of the water against the riser. Approximately 40,000 pounds of upward tension is required for safe operation in 1000 feet of water so it is rather easy to detect if the reentry probe has been locked into the reentry funnel by activating the riser tensioning system and then measuring the upward tension to the riser. The TV/sonar reentry tool is used to inspect the tree cap area and/or the area about the control pods if these are to be replaced. The TV/sonar tool 16 is then retracted into the riser 11 so that the running tool 54 can be used to remove the old tree cap and install a new one or the running

tool can be used to replace the control pod.

In order to replace the tree cap the running tool 54 is pulled down into the position shown in Figure 10 by the lowering rams 50*a*, 50*b* and lowered over the tree cap 34 with the inwardly projecting lug 42 riding in the groove 44 (Figs. 10 and 19). The old tree cap is removed and the lowering rams 50*a*, 50*b* are then collapsed so that the lug 42 moves to the upper end of the groove 44*a* on the probe 20. The upper end of the riser 11 is rotated clockwise so that the lug 42 moves into the groove 68 (Fig. 19), thereby positioning the old tree cap 34 and the running tool 54 over the storage depot 49*a* (Figs. 11 and 14). The lowering rams 50*a*, 50*b* are extended so that the old cap 34 is forced down onto the storage depot 49*a* (Fig. 12), the running tool 54 releases the old cap, and the running tool is then moved upward to the position shown in Figure 13.

If downhole work is required the running tool is positioned over the upper portion 29*a* of the subsea tree 29 and then locked and sealed to the subsea tree, during which any downhole wireline tasks are completed. After the completion of the downhole work the lowering rams are again collapsed so that the lug 42 moves to the upper end of the groove 44*a*. The riser 11 is rotated counterclockwise so that the inwardly projecting lug 42 moves into the groove 67 (Fig. 19) with the running tool directly above the new tree cap 34*a* on the storage depot 49*b* (Fig. 14). The running tool 54 is lowered onto the new cap 34*a* (Fig. 13) and the cap 34*a* is lifted off the storage depot 49*b*. The riser is rotated clockwise until the inwardly projecting lug 42 (on the lower guide sleeve 36*b*) moves into the center groove 44 on the reentry probe 20. The new tree cap 34*a* is lowered into position and locked onto the upper portion 29*a* of the subsea tree (Fig. 16). The TV/sonar tool 16 can again be extended from the lower end of the running tool 54 and the new tree cap installation inspected. If the tree cap is properly installed the probe latches 59 (Fig. 3) are released by hydraulic lines (not shown) which are connected between the tip 20*a* of the reentry probe and the surface vessel 12. The reentry probe 20, the riser 11, and the component manipulator 15 can be moved upward (Fig. 17) and returned into the surface vessel. It should be noted that the invention can be employed with a drill pipe or even with a flexible cable as well as a riser.

When it is desirable to replace both a tree cap and a control pod in a single trip to the seafloor, a second embodiment 20′ of the reentry probe is used. This reentry probe includes five separate grooves (Fig. 22) for guiding the inwardly projecting lug 42 of the lower guide sleeve 36*b* so that the running tool 54 may be positioned at any of five different locations about the reentry probe 20′ (Fig. 20). For example, the new tree cap may be stored on the storage depot 49*a* (Fig. 20) and a new control pod stored on the storage depot 49*b*. To reach the storage depot 49*a* (Fig. 20) the projecting lug 42 is moved into the groove 68*b* (Fig. 22); to reach the storage depot 49*b* the lug 40 is moved into the groove 67*b*; to reach the control pod 35*a* the lug is moved into the groove 68*a*; to reach the control pod 35b the lug 40 is in the groove 67*a* and to reach the old tree cap 34 the lug is moved into the groove 44.

In order to change the tree cap, to change a control pod, and do downhole work in a single trip of the riser down from the surface, the following sequence may be used. Let us assume that the tree cap 34 and the control pod 35b are faulty. With a new tree cap on depot 49*a*, and a new pod on depot 49*b*, and the probe 20′ locked into the funnel 21, the new control pod is moved from the depot 49b (Fig. 20) and stored on top of the good control pod on the tree. For example, the new pod is moved from the depot 49*b* and stored on top of the good pod 35*a*. The top portion of each of the control pods is shaped so that the bottom portion of another control pod can be forced down and locked upon it. The old tree cap 34 is moved onto the storage depot 49*b* and the running tool moved over the top of the tree so that the downhole work can be completed. When the downhole work is completed, the new tree cap is moved from the storage depot 49*a* onto the top of the subsea tree, the defective control pod 35*b* is removed from the tree and stored on the depot 49*b*. The new control pod is removed from its temporary storage position on top of the pod 35*a* and installed at the location where the pod 35*b* was removed. This is all done in one trip to the seafloor.

The present embodiment can also be used with subsea trees which are mounted below the mudline. It is also possible to reverse the positions of the probe 20 and the funnel 21 so that the probe is mounted on the subsea installation and the funnel is mounted on the lower end of the tubular column.

It is possible to use the probe 20 and the manipulator device 15 with a cable instead of a riser. A hydraulic motor can be connected between the probe 20 and the manipulator device 15 to rotate the manipulator about the probe. The probe 20, the cylinders 50*a*, 50*b*, the running tool 54, the guide sleeves 36*a*, 36*b* and other elements shown in Figure 5 can be connected to the lower end of a cable which is suspended from the surface vessel 12 (Fig. 1). Hydraulic lines can be connected from the surface vessel to the hydraulic cylinders 50*a*, 50*b* and to the

hydraulic motor (not shown). The probe can be lowered into the offset funnel 21 and the operation of the manipulator device 15 can be controlled in the manner described hereinbefore, the only difference being the use of the hydraulic motor to move the running tool in an arc about the probe 20.

Another embodiment of a completely guidelineless wellhead entry and reentry system is disclosed in Figures 25-37. The reentry probe 20 of Figures 1-22 has been modified into a considerably longer length by the inclusion of an extension 20c (Fig. 25) between the probe 20 and the tip 20*a*. This extension allows the probe to reach below the top of the wellhead to the seafloor. A second funnel 21' (Figs. 26-37) is mounted on a guidebase 23*a* to facilitate initial entry into the wellhead without the guidelines commonly employed prior to the installation of a subsea tree or a blowout preventer. The various steps of installing, using and servicing such a guidelineless wellhead system are shown sequentially in the Figures 26-37.

The guidebase 23*a* (Fig. 26) and a foundation casing 117 are attached to the drill riser 11 for landing on the seafloor 25. The TV/sonar reflectors 26*a* which are biased toward a vertical position by a plurality of springs 118 are folded inward toward the riser 11 during the time the guidebase is lowered through the moon pool or opening (not shown) in the bottom of the surface vessel 12 (Fig. 1). The foundation casing 117 is driven, or drilled into the seafloor 25 until the guidebase 23*a* is positioned on the seafloor 25 as shown in Figure 27. The casing and guidebase are cemented in place in the usual manner, and the reflectors 26*a* are moved into a vertical position about the guidebase. The drilling riser 11 is disconnected from the guidebase 23*a* and the riser is returned to the surface vessel 12.

The component manipulator device 15, the long probe 20*c* a blowout preventer 119 and the reentry funnel 21 are connected to the lower end of the drilling riser 11 (Fig. 28) and returned to a position a few feet above the entry funnel 21' using the TV/sonar tool 16 to direct the operation. The hydraulic lowering rams 50*a*, 50*b* are collapsed so that the probe 20*a* is lowered and locked into position inside the guidebase funnel 21' (Fig. 29). The blowout preventer 119 is then lowered into position (Fig. 30) and locked onto the guidebase 23*a* so that the drilling operation may be completed and the blowout preventer raised to the surface vessel 12 where the preventer is disconnected from the riser 11.

The subsea tree 29 is connected to the riser 11 and lowered to a position (Fig. 31) above the guidebase using the TV/sonar tool 16 extending from the lower end of the subsea tree as a means for guiding the tree into position. The probe 20*c* is again lowered into the base funnel 21' (Fig. 32) using the lowering rams 50*a*, 50*b*. The subsea tree is then guided into position, locked onto the upper end 117*a* of the casing 117 (Fig. 33), and the running tool 54 then disconnected from the upper end of the subsea tree 29 (Fig. 34). The running tool 54 moves to a storage depot (Fig. 35) to retrieve the cap 34 which is placed on the upper end of the subsea tree 29 as seen in Figure 36 to complete the installations of the subsea tree 29. The probe 20*c* is then released (Fig. 37) from the base funnel 21' and the riser 11 and component manipulator device 15 are returned to the surface vessel 12.

The present invention provides a simple means for entering or reentering a subsea wellhead without the use of guidelines between the wellhead and a surface vessel. TV/sonar equipment is used to direct the operating and service equipment into a position adjacent the wellhead. An offset funnel mounted on the wellhead and a probe mounted on a component manipulator device are used to accurately guide the manipulator device into working alignment with the various parts on the wellhead. Replacement parts are stored on depots on the manipulator device so that defective parts can be replaced and downhole work done on a well in a single trip to the seafloor. The present invention eliminates the problem of guideline cables being broken or dropped onto the seafloor especially when wells have been abandoned for a time and then reentry is desired.

Although the best mode contemplated for carrying out the present invention has been herein shown and described, it will be apparent that modification and variation may be made without departing from the invention as defined in the claims appended hereto.

WHAT WE CLAIM IS:

1. A guidelineless subsea wellhead entry system for use with an elongated column and a subsea well having a subsea installation attached thereto, said system comprising an elongate probe connected to said column and a funnel having a mouth portion whose axis is offset relative to the axis of a smaller neck portion of the funnel, said funnel being connected to said subsea installation, means for locating said subsea installation, and means for moving said probe and said column toward said funnel.

2. A guidelineless subsea wellhead entry system as claimed in claim 1 including means for securing said probe in position after said probe has been moved into said neck portion of said funnel.

3. A guidelineless subsea wellhead entry system for use with a tubular column and a

hydraulic motor (not shown). The probe can be lowered into the offset funnel 21 and the operation of the manipulator device 15 can be controlled in the manner described hereinbefore. the only difference being the use of the hydraulic motor to move the running tool in an arc about the probe 20.

Another embodiment of a completely guidelineless wellhead entry and reentry system is disclosed in Figures 25-37. The reentry probe 20 of Figures 1-22 has been modified into a considerably longer length by the inclusion of an extension 20c (Fig. 25) between the probe 20 and the tip 20*a*. This extension allows the probe to reach below the top of the wellhead to the seafloor. A second funnel 21' (Figs. 26-37) is mounted on a guidebase 23*a* to facilitate initial entry into the wellhead without the guidelines commonly employed prior to the installation of a subsea tree or a blowout preventer. The various steps of installing, using and servicing such a guidelineless wellhead system are shown sequentially in the Figures 26-37.

The guidebase 23*a* (Fig. 26) and a foundation casing 117 are attached to the drill riser 11 for landing on the seafloor 25. The TV/sonar reflectors 26*a* which are biased toward a vertical position by a plurality of springs 118 are folded inward toward the riser 11 during the time the guidebase is lowered through the moon pool or opening (not shown) in the bottom of the surface vessel 12 (Fig. 1). The foundation casing 117 is driven. or drilled into the seafloor 25 until the guidebase 23*a* is positioned on the seafloor 25 as shown in Figure 27. The casing and guidebase are cemented in place in the usual manner, and the reflectors 26*a* are moved into a vertical position about the guidebase. The drilling riser 11 is disconnected from the guidebase 23*a* and the riser is returned to the surface vessel 12.

The component manipulator device 15, the long probe 20*c* a blowout preventer 119 and the reentry funnel 21 are connected to the lower end of the drilling riser 11 (Fig. 28) and returned to a position a few feet above the entry funnel 21' using the TV/sonar tool 16 to direct the operation. The hydraulic lowering rams 50*a*, 50*b* are collapsed so that the probe 20*a* is lowered and locked into position inside the guidebase funnel 21' (Fig. 29). The blowout preventer 119 is then lowered into position (Fig. 30) and locked onto the guidebase 23*a* so that the drilling operation may be completed and the blowout preventer raised to the surface vessel 12 where the preventer is disconnected from the riser 11.

The subsea tree 29 is connected to the riser 11 and lowered to a position (Fig. 31) above the guidebase using the TV/sonar tool 16 extending from the lower end of the subsea tree as a means for guiding the tree into position. The probe 20*c* is again lowered into the base funnel 21' (Fig. 32) using the lowering rams 50*a*, 50*b*. The subsea tree is then guided into position, locked onto the upper end 117*a* of the casing 117 (Fig. 33), and the running tool 54 then disconnected from the upper end of the subsea tree 29 (Fig. 34). The running tool 54 moves to a storage depot (Fig. 35) to retrieve the cap 34 which is placed on the upper end of the subsea tree 29 as seen in Figure 36 to complete the installations of the subsea tree 29. The probe 20*c* is then released (Fig. 37) from the base funnel 21' and the riser 11 and component manipulator device 15 are returned to the surface vessel 12.

The present invention provides a simple means for entering or reentering a subsea wellhead without the use of guidelines between the wellhead and a surface vessel. TV/sonar equipment is used to direct the operating and service equipment into a position adjacent the wellhead. An offset funnel mounted on the wellhead and a probe mounted on a component manipulator device are used to accurately guide the manipulator device into working alignment with the various parts on the wellhead. Replacement parts are stored on depots on the manipulator device so that defective parts can be replaced and downhole work done on a well in a single trip to the seafloor. The present invention eliminates the problem of guideline cables being broken or dropped onto the seafloor especially when wells have been abandoned for a time and then reentry is desired.

Although the best mode contemplated for carrying out the present invention has been herein shown and described, it will be apparent that modification and variation may be made without departing from the invention as defined in the claims appended hereto.

WHAT WE CLAIM IS:

1. A guidelineless subsea wellhead entry system for use with an elongated column and a subsea well having a subsea installation attached thereto. said system comprising an elongate probe connected to said column and a funnel having a mouth portion whose axis is offset relative to the axis of a smaller neck portion of the funnel, said funnel being connected to said subsea installation, means for locating said subsea installation, and means for moving said probe and said column toward said funnel.

2. A guidelineless subsea wellhead entry system as claimed in claim 1 including means for securing said probe in position after said probe has been moved into said neck portion of said funnel.

3. A guidelineless subsea wellhead entry system for use with a tubular column and a

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subsea well having a subsea installation attached thereto, said system comprising a locking probe connected to said tubular column, a funnel having a mouth portion whose axis is parallel to but spaced from the axis of a smaller neck portion of the funnel, said mouth portion having an internal surface which slopes to facilitate movement of said probe, upon entry into said mouth portion, toward said neck portion, said neck portion having means for securing said probe in position after said probe has been moved into said neck portion; means for connecting said funnel to said subsea installation with the axis of said neck portion parallel to and spaced from the axis of the subsea well, means for locating said subsea installation and a component manipulator device, said locating means and said manipulator device being connected to said tubular column.

4. A guidelineless subsea wellhead entry system as claimed in claim 3 wherein said subsea installation locating means includes signal sending and receiving means.

5. A guidelineless subsea wellhead entry system as claimed in claim 4 including signal reflecting means and means for mounting said signal reflecting means adjacent said wellhead.

6. A guidelineless subsea wellhead entry system as claimed in claim 3 wherein said means for securing said probe include means for selectively latching said probe to said funnel.

7. A guidelineless subsea wellhead entry system as claimed in claim 4, claim 5 or claim 6 wherein said securing means include latching means for selectively latching said probe to said funnel and remote control means for operating said latching means.

8. A guidelineless subsea wellhead entry system as claimed in any of claims 3 to 6 including guide means connected between said probe and said manipulator device for positioning said manipulator device relative to said probe.

9. A guidelineless subsea wellhead entry system as claimed in claim 8 wherein said guide means includes rotational stop means for positioning said manipulator device in predetermined rotational positions about said probe.

10. A guidelineless subsea wellhead entry system as claimed in any of claims 3 to 8 wherein said manipulator device includes storage depots for holding replacement parts and a running tool for removing and installing said replacement parts.

11. A guidelineless subsea wellhead entry system as claimed in any of claims 3 to 10 wherein means connecting said probe to said tubular column includes means for raising and lowering said probe relative to the lower end of said tubular column.

12. A guidelineless subsea wellhead entry system as claimed in claim 11 wherein said means for raising and lowering said probe includes hydraulic power operated means and means for the remote control of said hydraulic power means.

13. A guidelineless subsea wellhead entry system as claimed in claim 8 wherein said guide means includes means for rotationally positioning said probe relative to said funnel and means for rotationally positioning said manipulator device relative to said probe.

14. A guidelineless subsea wellhead re-entry system for use with a riser and a wellhead having a subsea tree attached thereto, said system comprising a locking probe, a funnel having a mouth portion whose axis is spaced from the axis of a smaller neck portion of the funnel and a surface sloping downwardly from the mouth portion to the neck portion, said funnel being connected to said subsea tree; means for connecting said probe to said riser; means on the probe for selectively locking said probe in said neck portion of said funnel when said probe is properly positioned in said neck portion, a component manipulator device for connecting and disconnecting components from said subsea tree, signal sending and receiving means, means for connecting said manipulator device and said signal means to said riser, and signal reflecting means mounted on said subsea tree.

15. A guidelineless subsea wellhead re-entry system as claimed in claim 14 including means for positioning said manipulator device relative to said probe.

16. A guidelineless subsea wellhead re-entry system as claimed in claim 15 wherein said means for positioning said manipulator device includes means for raising and lowering said manipulator device relative to said probe and means for accurate rotational positioning of said manipulator device about said probe.

17. A guidelineless subsea wellhead entry system as claimed in claim 1 including a manipulator device, means for connecting said manipulator device to said elongated column, and means for positioning said manipulator device in a predetermined number of rotational positions about said probe.

18. A guidelineless subsea wellhead entry system as claimed in any of claims 3 to 13 wherein said means connecting said funnel to said subsea installation includes means for so mounting the said neck portion that its axis lies between the axis of said subsea well and the axis of said mouth portion of said funnel.

19. A guidelineless subsea wellhead entry system as claimed in claim 3 wherein the axis of said neck portion is adjacent an

outer edge of said mouth portion.

20. A guidelineless subsea wellhead entry system as claimed in any preceding claim wherein said probe, when positioned in said funnel, is located with its axis parallel to and spaced from the axis of said column.

21. A guidelineless subsea wellhead entry system as claimed in claim 14 wherein said funnel is located with the axis of said neck portion parallel to and spaced from the axis of said subsea tree.

22. A guidelineless subsea wellhead entry system as claimed in claim 19 including means for mounting said manipulator device with the axis thereof parallel to the axis of said subsea well and with one of said rotational positions coaxial with the axis of said subsea well.

23. A guidelineless subsea wellhead entry system for use with an elongated column and a subsea well having a subsea installation attached thereto, said system comprising an elongated probe, a funnel having a mouth portion and a smaller neck portion, the axis of said neck portion being parallel to and spaced from the axis of said mouth portion of said funnel, one of said probe and funnel being connected to said subsea installation, the other being connected to said column, means for locating said subsea installation, and means for moving said probe and said column relatively toward one another.

24. A guidelineless subsea wellhead entry or re-entry system substantially as hereinbefore described with reference to the accompanying drawings.

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