Nov. 23, 1965 G. E. LEWIS 3,219,118

SUBMARINE WELL HEAD TOOL SERVICING APPARATUS

Filed Jan. 12, 1962 5 Sheets-Sheet 1

FIG. 1.

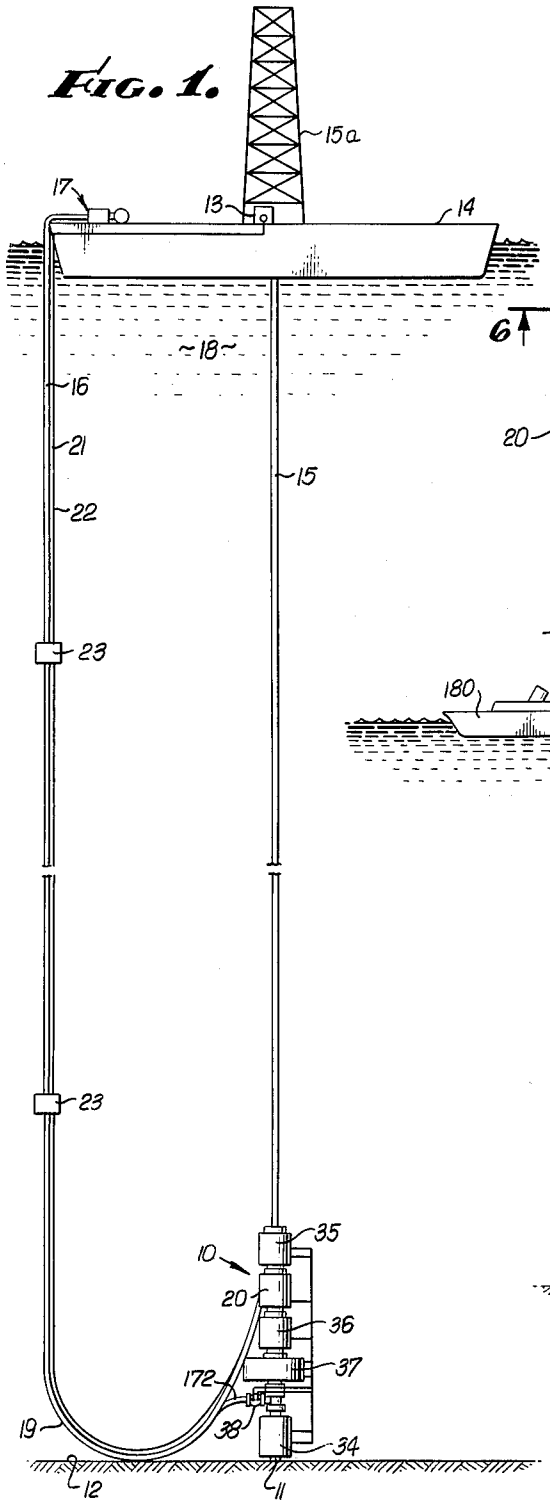


FIG. 7.

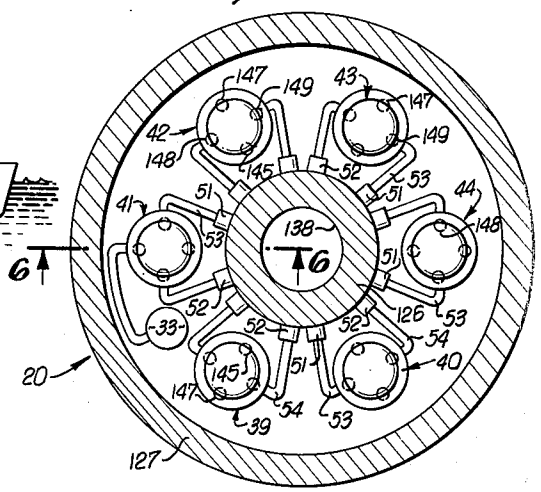
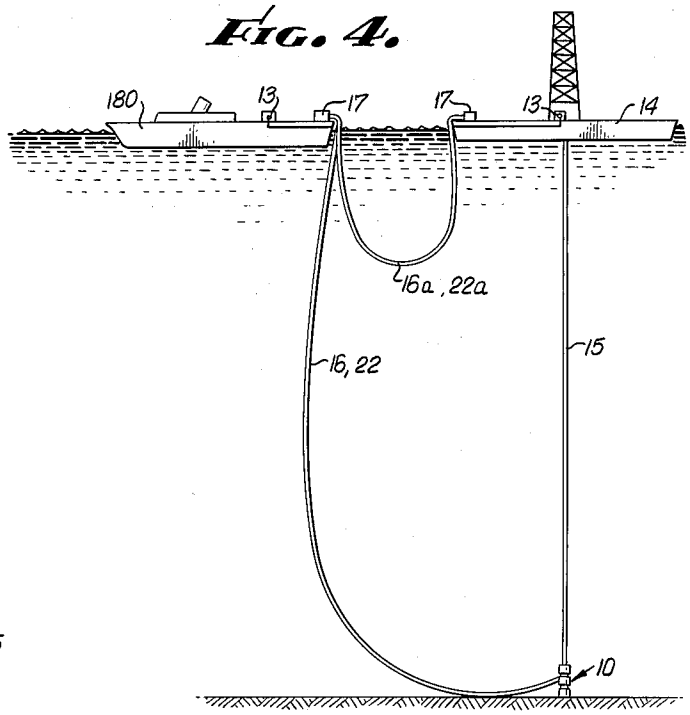


FIG. 4.



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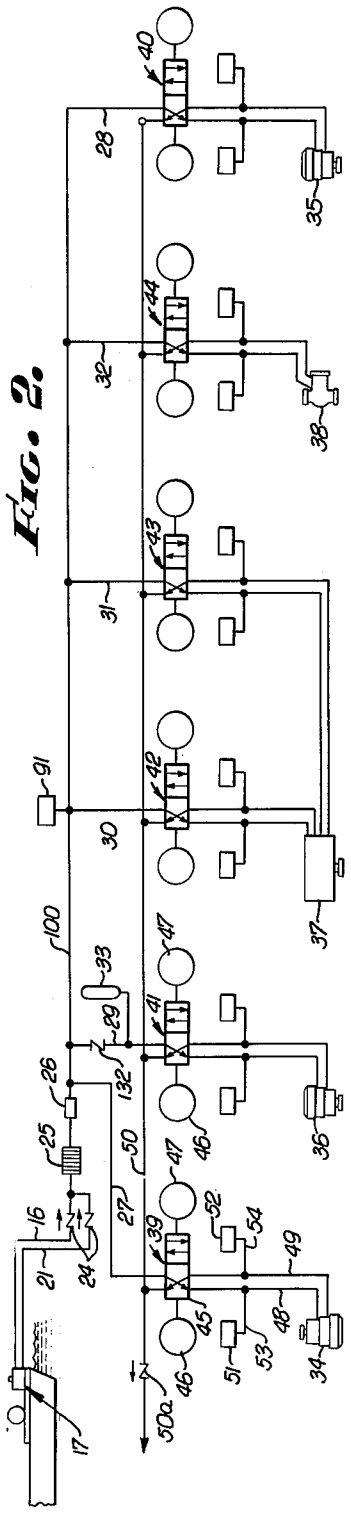


FIG. 2.

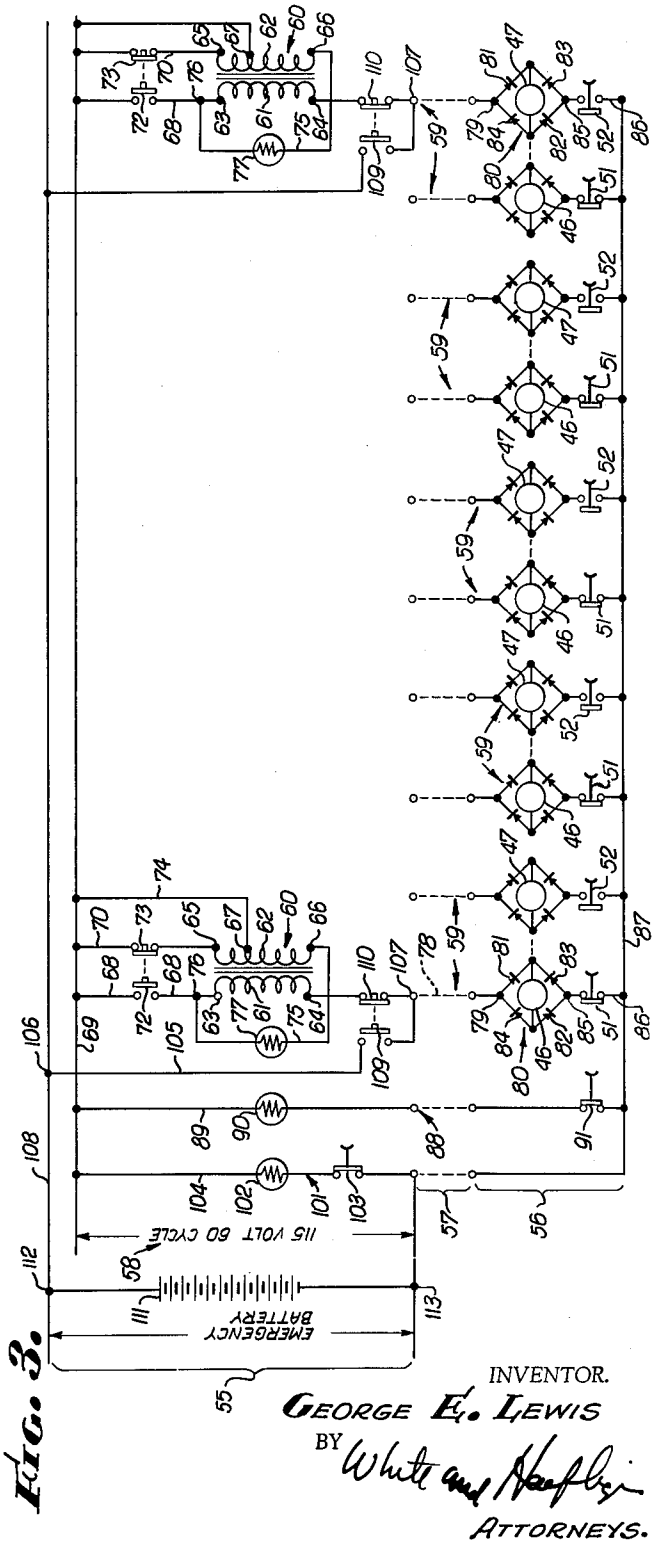


FIG. 3.

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SUBMARINE WELL HEAD TOOL SERVICING APPARATUS

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FIG. 5.

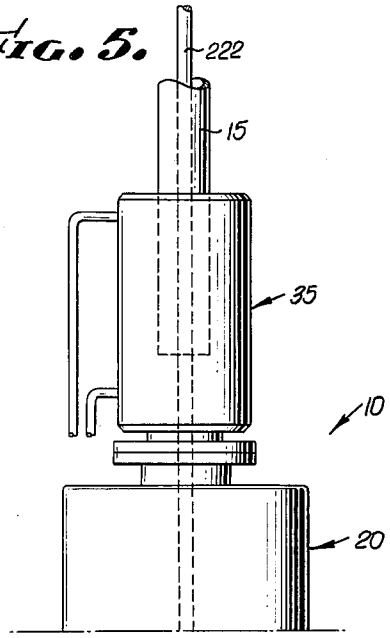


FIG. 5a.

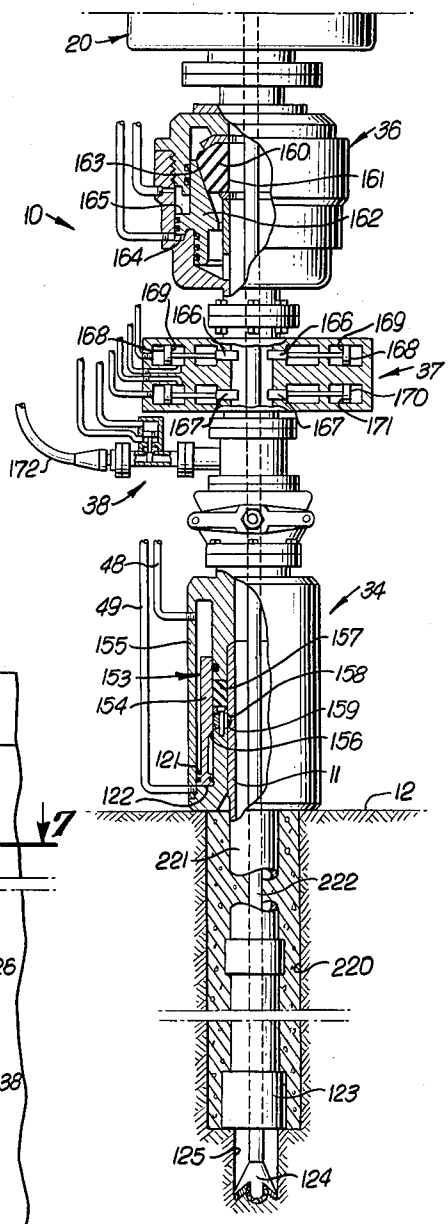
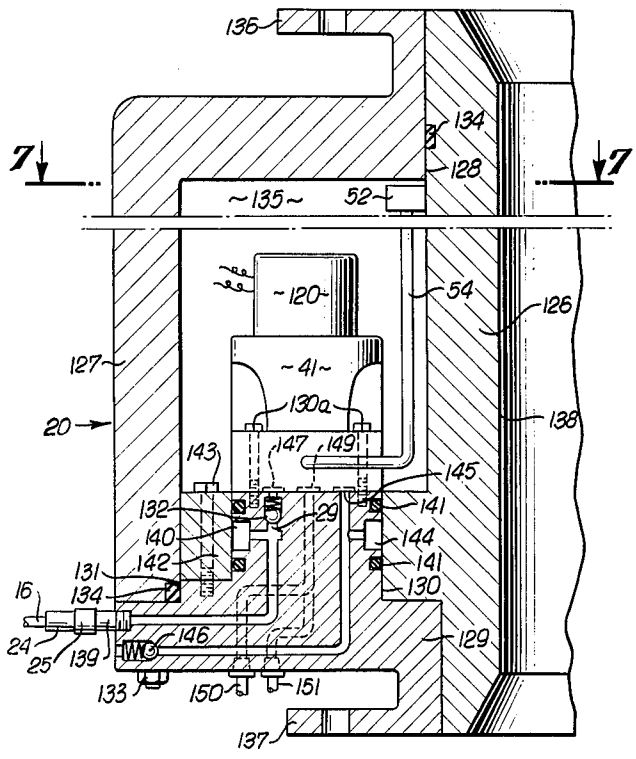


FIG. 6.



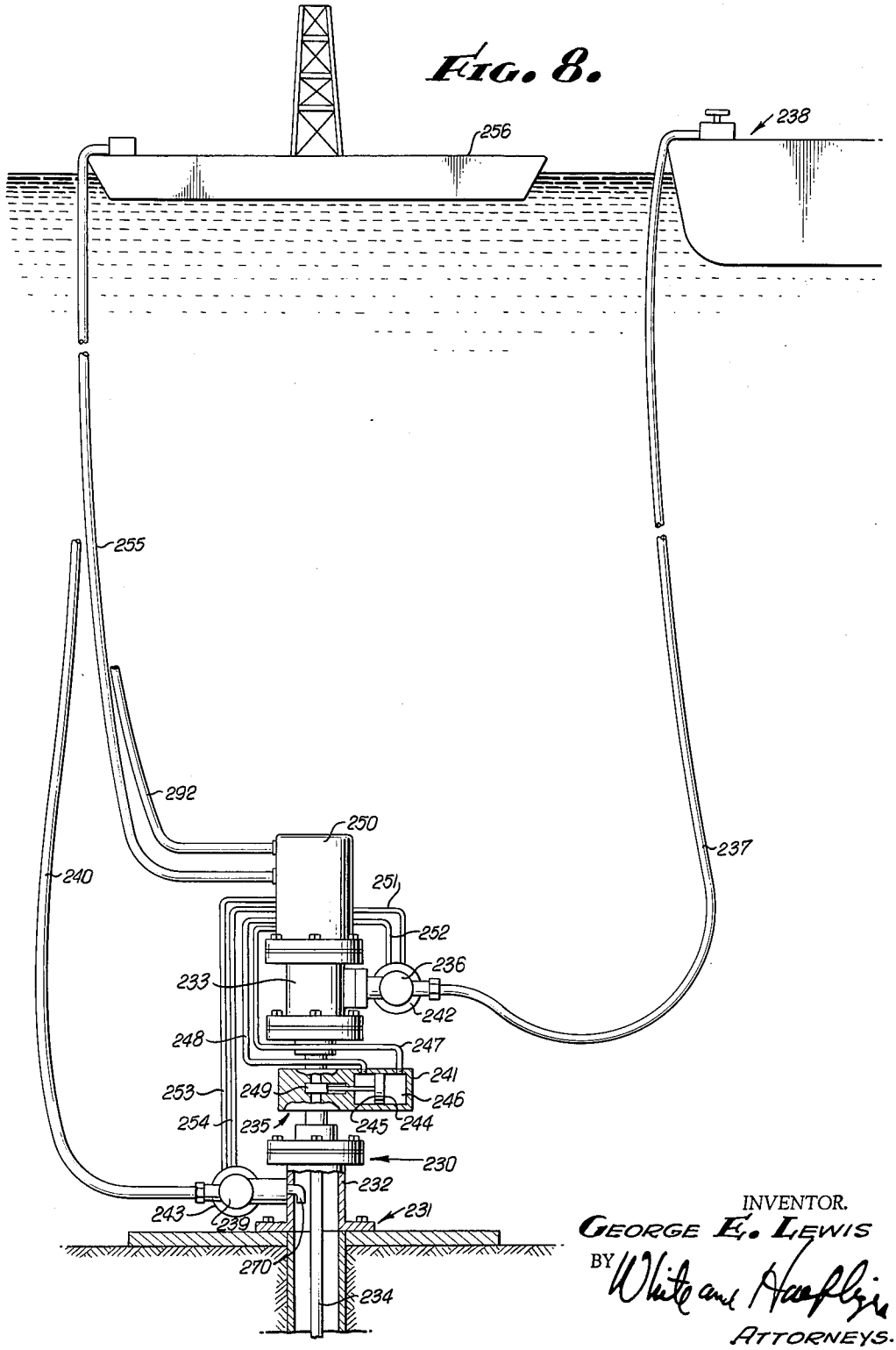
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SUBMARINE WELL HEAD TOOL SERVICING APPARATUS

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FIG. 8.



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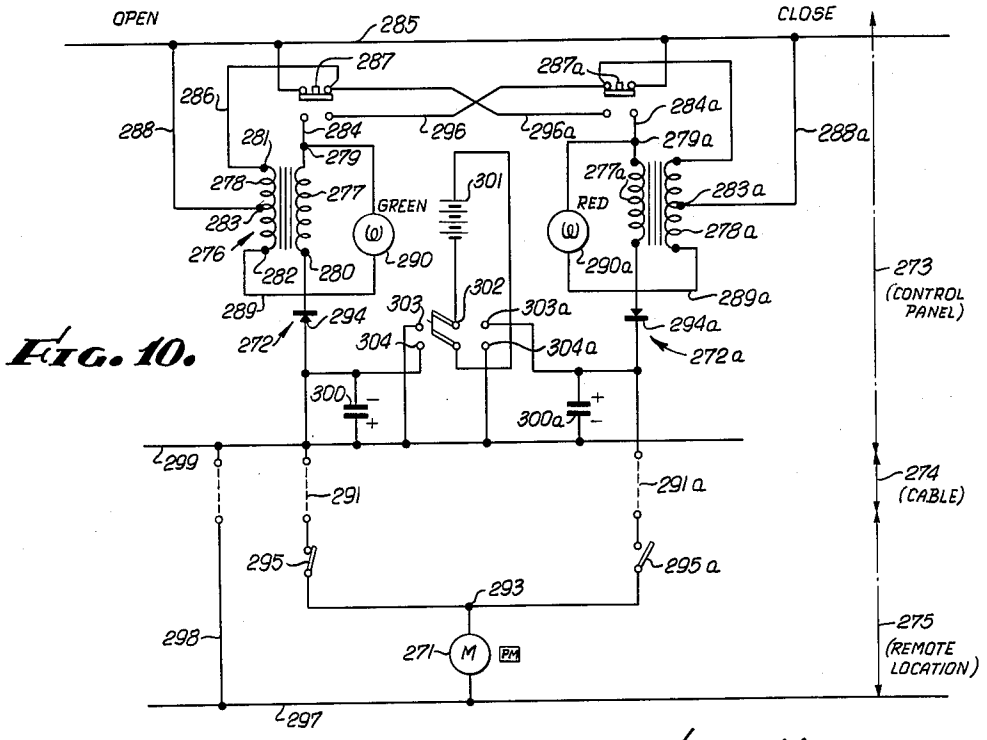


FIG. 10.

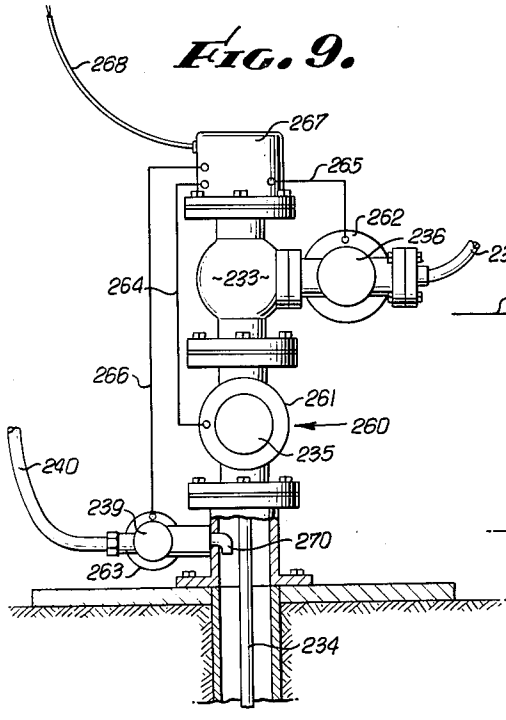


FIG. 9.

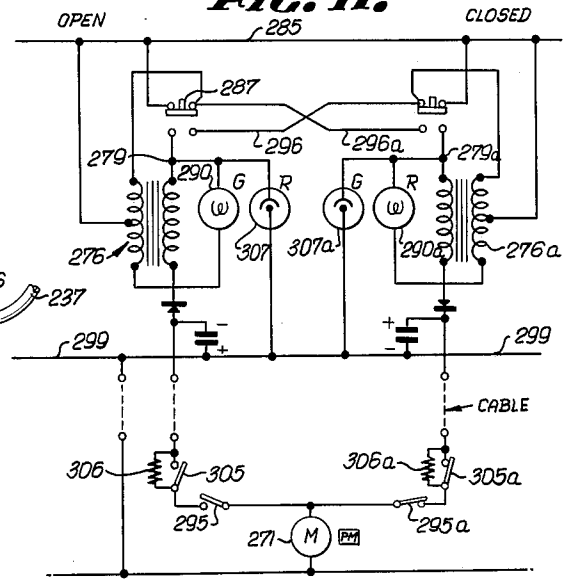


FIG. 11.

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United States Patent Office 3,219,118 Patented Nov. 23, 1965

3,219,118

SUBMARINE WELL HEAD TOOL SERVICING APPARATUS

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Filed Jan. 12, 1962, Ser. No. 165,742
18 Claims. (Cl. 166—66.5)

This invention relates generally to the control of underwater well heads, and more particularly concerns what may be characterized as submarine well head tool servicing apparatus and completion assemblies.

In certain underwater well drilling or producing operations it is desirable to service the well as by means of a tool or a string of tools connectible to a projecting well fitting, such as a submarine stub casing terminating above the ocean floor. As an example, where well casing has already been sunk in the submarine hole with the free end of the casing projecting above the ocean floor, it is desirable to provide for the controlled operation of blow-out prevention equipment, safety valves, safety joints or connectors, as well as other auxiliary apparatus, all connected in a string and attached to the projecting well casing, in order to serve the well. Commercial equipment of this nature is generally fluid pressure operated, and it has heretofore been considered necessary to provide a bundle of separate pressure hoses or conduits extending underwater from a surface location to the tools so that independent operation thereof might be achieved as desired. However, the large number of hoses required to supply fluid pressure to multiple tools at the underwater well head creates problems such as the tendency of underwater currents to deflect pressure lines or conduits, such deflection being greater as the size of the hose bundle increases, and such deflection creating further problems of entanglement with underwater equipment, the considerable weight of all the hoses, particularly where the submarine well head is several hundred feet below the surface, and the tendency of the water pressure at greater depths to collapse the flexible fluid pressure conduits. Also, the greater number of fluid pressure lines the greater is the risk of rupture of one or more such lines, leading to stoppages in drilling or producing the well.

The present invention offers a solution to these and other problems through the substantial reduction of long multiple pressure lines independently serving different tools in an underwater string. Such a string may include tools operable during the underwater well drilling phase, as for example blow-out prevention equipment and the like, or as another example may include tools such as valves or a pressure chamber operable during the underwater well completion phase, as will be described. As broadly conceived, the invention makes possible the use of a single fluid pressure supply conduit extending below the water surface to the well head location, by providing electrically responsive means at the well head for controlling the flow of fluid between the single pressure conduit and the different tools, together with circuit means including cable extending underwater for electrical connection with the electrically responsive means to control energization thereof, thereby controlling the operation of the different tools to service the well as desired, such operation being indicated at the surface. As will appear, the underwater cable which replaces the parallel pressure lines is much better adapted for underwater use since it is more reliable than multiple pressure lines, presents much less side loading area to underwater currents so that underwater deflection is reduced, and there is no problem of collapsing of the cable due to underwater pressure.

In addition to the foregoing, the invention makes possible one-way delivery of fluid pressure to the well head location for all tool servicing requirements, there being no need for return lines to conduct fluids exhausting from the tools back toward the surface, as has previously been required. This desirable result is brought about through the combination of electrically responsive means such as electrical prime mover operated valves at the well head for controlling fluid pressure application to and fluid pressure escape from the different tools, together with porting through which fluid may escape from the tools to the sub-surface water as controlled by such valves. Accordingly, the system is considerably simplified as respects the delivery and handling of fluid pressure required for operating the tools, which decreases significantly the risk of malfunction of the equipment.

A further important aspect of the invention concerns the provision of multiple circuit sections for selectively controlling energization of the underwater valve prime movers to operate the valves to the desired multiple positions corresponding to desired configurations of the tools. Typically, two current supplying circuit sections are electrically connected with each valve prime mover or motor, the sections including power switch means at the surface station to control energization of the prime mover for operating the valve between first and second positions corresponding to desired operating configurations of the tool. Each circuit section may include an indicator at the surface station operable to test the circuit section as respects circuit completion to the underwater valve prime mover during both stand-by and operating phases, the indicator also being operative to indicate switch opening of the circuit section in response to predetermined build-up of fluid pressure application to the tool, which fluid pressure build-up operates a sub-surface switch in the circuit section.

Further features and advantages of the invention include the provision of an underwater fluid pressure accumulator connected in pressure supplying relation with the underwater valves, the provision for emergency D.C. power supply to the circuit sections in the event A.C. power supply thereto fails, the provision for sub-surface rectification of the A.C. power supply, and the provision for multiple surface control stations on different vessels from one of which pressure supply conduit is suspended along with the underwater transmission cable, and from the other of which a well pipe string is extensible downwardly to the sub-surface well head, an extension of the transmission cable being suspended underwater and between the two vessels.

These and other objects and advantages of the invention, as well as the details of an illustrative embodiment will be more fully understood from the following detailed description of the drawings, in which:

FIG. 1 is an elevation showing a string of well servicing tools at a submarine well head location, and beneath a servicing vessel;

FIG. 2 is a diagrammatic presentation of the fluid pressure system;

FIG. 3 is a diagrammatic presentation of the electrical system;

FIG. 4 is a view like FIG. 1 showing the manner in which the string of well servicing tools may be controlled from separate stations on different vessels;

FIG. 5 and FIG. 5*a* show an elevation, partly in section, taken through a typical string of well servicing tools;

FIG. 6 shows a sectional elevation of a manifold chamber to be incorporated with a string of tools;

FIG. 7 is a reduced size section taken on line 7—7 of FIG. 6;

FIG. 8 shows an underwater well completion unit controlled in accordance with the invention;

FIG. 9 shows a modified well completion unit controlled in accordance with the invention;

FIG. 10 is a control circuit adapted for use to control the FIGS. 8 and 9 completion units; and

FIG. 11 is another circuit for controlling the FIGS. 8 and 9 units.

Referring first to FIG. 1, a string of fluid pressure operable well servicing tools is generally designated by the numeral 10 at a submarine well head location, the well head being identified by a casing stub **11** which projects above the ocean floor **12**. The tool string **10**, which is more completely shown in FIGS. 5 and *5a*, typically comprises an integrated assembly of tools to be controlled from the ocean surface, as represented by well tubing extending downwardly within upper casing **15** below a derrick **15***a* on the vessel, and to the tool string **10**.

Fluid pressure is delivered by means including supply conduit **16**, usually flexible, which extends downwardly from a surface accumulator unit **17** and below the surface of the ocean **18** to ultimately bend at **19** toward the tool string near the ocean floor. FIG. 1 shows the fluid pressure delivery means to include an underwater fluid pressure manifold chamber **20** connected in the tool string **10** for receiving fluid pressure from the conduit **16**. In accordance with the invention only one fluid pressure conduit **16** need be provided, although the invention contemplates the provision of an auxiliary or stand-by conduit for use in the event of malfunction of the conduit **16**. Such a stand-by conduit **21** as well as the principal conduit **16** are shown diagrammatically in FIG. 2.

As will be described, electrically responsive means, typically including electrical prime mover operated valves located in the manifold chamber **20**, are provided for controlling the flow of fluid pressure via the fluid pressure delivery means to the tools in the string **10**. Energization of the electrically responsive means is controlled by circuit means which includes cable **22** extending below the water surface for electrical connection with the electrically responsive means. Such cable is shown in FIG. 1 as running alongside the conduit **16**, the cable typically including parallel transmission lines or wires through which current is flowable to the valve prime movers integrated within the manifold chamber **20**. It will be understood that operation of the valve prime movers, or their equivalents, is electrically controlled from the station **13**, as will be described.

FIG. 1 also shows the use of floats such as float chambers **23** located at different elevations below the ocean surface and suitably connected to the cable and conduit group or bundle. Such floats are useful to relieve the hanging load imposed on the conduits **16** and **21** and cable **22** by suspension of extreme lengths of the cable and conduit, where the string **10** to be serviced is located at extreme depths.

Turning now to FIG. 2, it will be seen that fluid pressure is supplied downwardly through the hose or conduit **16**, or alternatively through the stand-by conduit **21**, through check valves **24**, filter **25**, flow bean **26** and then to pressure line **100** from which branch pressure lines **27** through **32** are supplied with fluid pressure. An accumulator **33** is connected into the system of pressure lines in such a way as to supply a blow-out preventer unit **36** with near-by, stabilized fluid pressure in sufficient volume to secure the desired quick and positive operation of that particular tool, and also to receive overflow pressure from lines **27** through **32** through a check valve **132**.

Although many different pressure responsive tools may be included in the tool string, the latter typically includes lower and upper well head connectors or safety joints **34** and **35**, well blow-out preventers **36** and **37** and a "kill-line" or mud valve **38**, all of which will be described later in greater detail. Connected in the string along with the operating tools is a manifold chamber **20** typically housing the accumulator and a system of electrical prime mover valves generally designated at **39** through **44**, which valves are connected in pressure application controlling relation with the tools **34** through **38** respectively.

Each of the valves is typically of four-way construction (but in some applications may be a three-way or shut-off valve) as diagrammatically illustrated by the arrows within the representation of a valve body **45**. The electrically responsive valve operating prime mover may typically comprise individual prime movers which are designated at **46** and **47**, and these may be of any suitable type such as solenoids which are useful for actuating gate-type values. The prime movers may alternately comprise electrical motors for actuating rotary-type valves such as are seen in FIGS. 6 and 7. In the configuration of the representative valve **39** illustrated, fluid pressure is supplied via line **27** and through the valve to the line **48** to a first actuating surface **121** (seen in FIG. *5a*) within the well head connector **34**. At this time, fluid may escape away from a second actuating surface **122** within the connector body **34** through a line **49** and through the valve **39** to sub-surface discharge porting represented at **50** for delivering exhausted fluid pressure to the ocean through check valve **50***a*. Conversely, when the valve **39** is actuated to its alternate position, fluid pressure will be delivered from line **27** to line **49** and to the mentioned second actuating surface **122** within the connector housing, and at such times pressure may escape away from the first actuating surface **121** through line **48** to the porting **50** and check valve **50***a* for discharge to the sea. The described operation is also characteristic of the operation of the other valves **40** through **44**, and of the tools **35** through **38**. Accordingly, the system is so constructed that fluid pressure delivery is essentially one-way, no return lines for carrying fluid pressure back to the surface being required.

Also, the check valves **24** prevent release of pressure from the accumulator **33** and the tools in the event of accidental overhead rupture of the pressure conduit **16**, as by storm action, and the filter **25** prevents flow of foreign pieces of solid material to the valves and tools, which material might otherwise clog these elements to the point of malfunction.

Finally, FIG. 2 illustrates the provision of pressure switches diagrammatically shown at **51** and **52** to be actuated in response to predetermined build-up of fluid pressure application through the lines **48** and **49** to the respective actuating surfaces within a tool. Accordingly, upon predetermined build-up of such pressure application through line **48**, the switch **51** will be actuated or tripped for purposes to be described, since the pressure in the line **48** will be applied to the switch **51** through the branch line **53**. The same is true as respects application of predetermined pressure to the switch **52** via branch line **54** connected into pressure line **49**.

Turning now to FIG. 3, the electrically responsive valve prime movers are schematically shown again in pairs at **46** and **47**, the remainder of FIG. 3 being for the most part devoted to an illustration of the circuit means operable to control energization of the valve prime movers or their equivalents. That portion of the circuit means included within the bracket **55** will be understood as being at the surface, that portion of the circuit means included within the bracket **56** is underwater and typically at the well head, and finally the circuit portion included within the bracket **57** will be understood as comprising conductor wires incorporated within the cable **22** shown in FIG. 1.

Considered on an overall basis, the FIG. 3 circuit comprises a number of parallel circuit sections normally supplied with power from an alternating current source **58**. The circuit sections include multiple like sections generally shown at **59** and grouped in pairs, so that two of the sections **59** are electrically connected with the respective prime movers **46** and **47** operable upon a single valve

such as the valve 39 previously described. Accordingly, one circuit section 59 is electrically connected with the prime mover 46, and another section is electrically connected with the prime mover 47.

That portion of each circuit section at the surface includes an iron core transformer 60 having primary and secondary coils 61 and 62, coil 61 having end terminals 63 and 64 and coil 62 having end terminals 65 and 66 as well as an intermediate tap or terminal 67. A line 68 connects terminal 63 with the main power line 69 supplying all the circuit sections, and a line 70 connects terminal 65 with the main line 69.

Switches 72 and 73 are respectively connected into the lines 68 and 70 in such a way that when switch 73 is closed switch 72 is opened, and vice versa. The intermediate tap or terminal 67 of the coil 62 is connected via line 74 with the main power line 69, and another line 75 is run from terminal 66 of coil 62 to terminal 76 in line 68, there being an indicator light 77 connected in series in the line 75. Finally, terminal 64 is connected through a transmission line 78 in the cable 22 with the terminal 79 of a rectifier bridge 80, the latter incorporating rectifiers 81 through 84 interconnected as shown and with the prime mover 46. The rectifier bridge terminal 85 is connected through the pressure switch 51 in line 86 with the power supply return line 87.

Considering the stand-by operation of the like pair of circuit sections 59 it will be understood that during the positive half of the A.C. cycle, current is supplied from the lead 69 through the line 70 and closed switch 73, then through the transformer coil 62, line 75, light 77, to terminal 76, then through the transformer coil 61 to terminal 64. The circuit is completed by passage of current from terminal 64 downwardly through the transmission line 78 to the bridge terminal 79, then through rectifier 81, prime mover 46, rectifier 82, closed switch 51 in line 86, and to line 87 for return to the power supply. On the negative half of the cycle, current passes through the rectifier 83, prime mover 46 and rectifier 84 back upwardly through the transmission line and through the circuit elements previously described, to the power supply line 69. Accordingly, the unit 80 operates as a full-wave bridge rectifier. Since the alternating current passes through the impedances offered by the coils 61 and 62 as well as through the impedance offered by the light or other indicator 77, the latter burns with less than full brilliance, and the power supplied to the prime mover 46 is less than required to effect operation thereof.

When operation of the prime mover 46 or 47 is desired, the switch 72 at the surface station is closed, and switch 73 is opened, typically manually. Accordingly, current now flows through line 68, coil 61 and directly to transmission line 78 and through the rectifier bridge and the prime mover. Since there is now substantially less effective impedance presented by these circuit elements, the power supplied through the prime mover 46 is sufficient to secure actuation thereof. At the same time, the current passing through the coil 61 of the transformer causes, by transformer action, a voltage to be produced in the coil 62. The latter voltage then causes a current to flow through the line 75 and the indicator 77, then through terminal 76 and lines 68, 69 and 74 back to the terminal 67 of the coil 62. Under these conditions the lamp or indicator 77 burns with relatively greater brilliance. Accordingly, during both stand-by and operating phases as respects the condition of the prime mover, the indicator 77 tests the circuit section 59 and the operator at the surface station 13 may at a glance inform himself as to the ability of the circuit to function as required.

From the foregoing it will be understood that closing of the switch 72 serves to operate a prime mover 46 to accomplish closing of the tool such as the blow-out preventer 36, whereas closing of the switch 73 accomplishes stand-by testing condition of the circuit. Under the latter conditions, the circuit section 59 associated with the prime mover 47 may be activated to open the blow-out preventer 36. In like manner, the other pairs of circuit sections 59 may be energized so as to secure operation of the other tools, as for example opening and closing of the pipe rams associated with the blow-out preventer 37, opening and closing of the blind rams associated with the blow-out preventer 37, opening and closing of the kill line valve 38, and connection and disconnection of either of the well head connectors 34 and 35, as will be described. In this connection, the pressure switch 51 or 52 in each circuit section 59 will, upon opening in response to predetermined build-up of pressure application to the tool, open the associated circuit section 59 thereby to interrupt current flow through the indicator 77 for notifying the operator of said changed pressure condition. It will be further noted that pressure lines 48 and 49 will alternately contain pressure and therefore when switch 51 is closed switch 52 will be open and vice versa. Accordingly, the operator will know that a particular tool has functioned correctly when the indicator light associated with that tool operation goes off. Further description of the basic circuitry is found in U.S. Patent 2,872,940.

Another circuit section 88 is shown in FIG. 3 as including a line 89 connected across the main power lines 69 and 87 in order to test the pressure in the supply line 100 at the bottom. For this purpose, a pressure switch 91 has pressure connection to the line 100 at the bottom, and has electrical connection into line 89, all in such manner that the switch 91 will open in response to predetermined droppage or build-up of pressure, as desired, in the line 100. Such predetermined droppage or build-up will then be denoted by the indicator 90 connected in series with switch 91.

A final circuit section 101 is connected across the power source at the surface, that section incorporating an indicator 102 and a pressure switch 103 both in series in a line 104, with the pressure side of the switch communicating with the pressure conduit 16 at the surface. Accordingly, this pressure switch and indicator may utilized to indicate a predetermined build-up or loss of fluid pressure in the conduit 16 as measured at the surface in the same manner as described above.

FIG. 3 also illustrates the provision for emergency D.C. power application to the prime movers in the circuit sections 59, in the event the alternating current source fails. For this purpose, a D.C. line 105 is connected between terminals 106 and 107 respectively located in D.C. power line 108 and transmission line 78. Closure of a switch 109 connected in the line 105 accomplishes D.C. energization of the transmission line 78, and at the same time a switch 110 connected between terminal 64 and 107 is opened to prevent interconnecting of the D.C. and A.C. current supplies. The D.C. source 111 has terminals 112 and 113 to which lines 108 and 87 are effectively connected.

Referring now to FIGS. 5 through 7, a drill hole 220 sunk below the ocean floor contains casing 221 typically cemented in position below the upwardly projecting casing stub 11, for further suitable drilling or producing operations. Drill pipe or tubing 222 extends downwardly within upper casing 15, through the tool string 10, the lower casing 221 and the casing shoe 123, for turning a drill bit 124 in the bottom hole 125.

As previously mentioned, operation of the tools 34 through 38 in the tool string 10 is accomplished by pressure servicing them from a manifold chamber 20 in the string. One form of such a chamber is shown in FIG. 6 to comprise inner and outer annular body parts 126 and 127 interfitting at 128, and an annular cap 129 interfitting parts 126 and 127 at 130 and 131 respectively. Suitable fasteners 133 and seals 134 are provided to hold the body parts together and to seal off access of ocean water to the interior 135 of the chamber 20. The

chamber has end flanges 136 and 137 for bolting onto corresponding flanges of other tools as shown in FIG. 5, and a central opening 138 through the chamber is provided to pass the tubing 222. Mounted on the cap 129 as by fasteners 130*a* are the housings of the circularly spaced four way rotary type valves 39 through 44, these being contained within the chamber interior and in turn mounting the valve prime movers in the form of reversible electric motors 120. The pressure switches 51 and 52 associated with each valve are also contained within the chamber interior, as shown.

The cap 129 contains a pressure inlet duct 139 communicating between check valves 24 and filter 25 and an annular recess 140 corresponding to the pressure line 100 in FIG. 2. From the recess 140 pressure lines 27 through 32 deliver pressure fluid to the valves 39 through 44 having inlet ports 147, one line 29 being illustrated in FIG. 6 and containing the check valve 132 also referred to in FIG. 2. Suitable seals are shown at 141 for sealing off between the cap and an annulus 142 which together with the cap form the recess 140. The annulus 142 is detachably secured to the cap as by means of a series of fasteners 143.

The cap 129 also contains an annular recess 144 corresponding to the discharge line 50 in FIG. 2. The recess 144 communicates with discharge ports 145 of the valves 39 through 44 and also with the exterior of the chamber 20 through check valve 146, which prevents reverse flow of sea water from the exterior back to the valves 39 through 44.

Each of the valves also contains ports 148 and 149 through which pressure is alternately transmissible to the corresponding pressure actuated tool in the string 10. These ports communicate with corresponding lines 150 and 151 in the chamber cap 129, and through appropriate ducts as illustrated, in order that lines may be connected from the ports 150 and 151 to the tools as shown in FIG. 5.

Referring now to FIGS. 5 and 5*a*, the lower and upper well head connectors or slips 34 and 35 respectively serve to detachably connect the string 10 onto the stub casing 11 and to the lower terminal of the upper casing 15 with which the connectors telescopically interfit. The connectors 34 and 35 may each have the construction shown in U.S. Patent 2,962,096, issued November 29, 1960 to Granville S. Knox. Briefly, each connector includes pipe slip structure 153 movable within a housing 155 between pipe gripping advanced position, as illustrated, and pipe releasing retracted position, in response to application of fluid pressure from the manifold, as controlled by a prime mover operable valve. Thus, the structure 153 in the connector 34 is controlled by the valve 39, whereas the slip structure 153 in the connector 35 is controlled by the valve 40. The structure 153 includes a cylindrical plunger unit 154 movable axially within the cylindrical housing 155 in response to fluid pressure application to one or the other pressure surfaces 121 and 122 associated with the plunger unit. Thus, pressure exertion against surface 121 moves the unit 154 forwardly, so that a cam surface 156 thereof successively urges a sealing annulus 157 against the casing to create a pressure seal, and then displaces a circular series of locking elements 158 laterally into locking engagement with the casing. As shown in FIG. 5*a* the elements 158 typically enter a groove 159 in the casing to create the interlocking condition preventing separation of the connector from the casing. Opposite pressure exertion against the surface 122 releases the interlocking condition and also the sealing engagement of the member 157 with the casing, to permit separation of the connector and the string from the casing. Accordingly, it will be understood that the tool string 10 may be detachably connected to or released from the casing stub 11 and also the lower terminal of the upper casing 15, as described. Thus, the upper casing 15 may be released from the tool string to permit upward withdrawal of the casing 15, and also to permit upward withdrawal of the string 10 after release from the stub casing 11, through disconnection of the slip 34 therefrom.

Referring to the blow-out preventer unit 36, it may be of the type shown in U.S. Patent 2,609,836, issued to Granville S. Knox, and is capable of completely closing off all fluid flow upwardly from the well whenever desired and regardless of whether or not the drill pipe or tubing 222 is positioned within the preventer. This device 36 may be typically described as including a massive annular rubber sealing element 160, containing an opening 161 through which the drill pipe 222 or other well apparatus may extend downwardly. The element 160 is adapted to be constricted or cammed radially inwardly to a closed bore sealing condition by upward movement of an actuating piston 162 engaging the element 160 at conical interface 163. The piston is actuable upwardly in response to pressure fluid admission to the underside 164 of the piston. Conversely, the piston is actuable downwardly to its bore open position by pressure fluid admission to the upper side 165 of the piston. The rubber element 160 is sufficiently deformable to conform to and form a seal with the outer surface of any size drill pipe, enlarged joint, non-circular part, or other member which may be received within the preventer. Further, if no such member is present in the preventer when the piston 162 is actuated upwardly, the piston movement continues upwardly until the central opening 161 is completely closed.

Referring to the secondary blow-out preventing unit 37, it may also be of conventional construction, described very generally as including an upper pair of horizontally opposed fluid pressure actuated pipe rams 166, and a lower pair of horizontally opposed "blind rams" 167, also pressure actuated. When pressure is applied against the upper ram piston surfaces 168, the upper rams are actuated relatively together and against the drill string or other pipe 222, so that semi-circular recesses in the two rams 166 embrace the pipe and form a fluid tight seal. Pressure fluid admission to the upper ram piston surfaces 169 causes relative separation of the upper rams. The second set of rams 167 is similar to the rams 166 with the exception that they are "blind" so as to completely close the bore when no pipe or other member is present within the preventer. The latter two rams are actuable relative together in response to application of pressure against the piston surfaces 170, and are actuable apart by pressure fluid admission against the piston surfaces 171.

FIG. 5*a* also shows a "kill-line" valve 38 for controlling removal of mud and gas through auxiliary line 172 and the valve from the interior of the string. The gate-type valve 38 contains pressure surfaces for actuating the gate between open and close positions to control introduction of mud to the well in the event it becomes necessary to kill pressure in the well after the blow-out preventers have been closed. Line 172 may extend to the ocean surface alongside conduit 16 previously described.

FIG. 4 illustrates the provision of multiple surface control station 13 and accumulators 17 on a drilling vessel or barge 14 and on a vessel 180. The pressure conduit 16 and the electrical cable 22 run upwardly from the tool string 10 to the vessel 180 for connection to the accumulator 17 and control station 13 thereon, and they also include extensions 16*a* and 22*a* running to the accumulator 17 and control station 13 on the drilling structure 14. Extensions 16*a* and 22*a* hang downwardly into the ocean so as to permit passage of other vessels thereover without severing thereof. Should either of the stations 13 or accumulators 17 be damaged, as for example due to damage to vessel 180 or 14, control of the underwater tool string 10 may then be maintained from the undamaged station.

Referring next to FIG. 8, a well completion unit is generally designated by the numeral 230 at a submarine well head location, the well head being identified at 231. The unit 230 includes a vertical series of chamber sections 232 and 233 as illustrated, with a well fluid production

pipe 234 extending upwardly from the well head to communicate with a main valve 235 operable to open or close off the flow of well fluid. Another valve is shown at 236 at the side of chamber 233 for accurately controlling the flow or production from the well to a production conduit 237 which may be flexible as illustrated, and extending upwardly to a tanker or other storage means indicated at 238. The remaining valve shown at 239 is operable to control the flow of mud or other fluid to or from the delivery line 240 to the interior of the chamber 232 and outside the pipe 234. Accordingly, the well valves 235, 236 and 239 may be considered as tools operable to service the well at the submarine well head location.

Each of the valves 235, 236 and 239 is operated by a fluid pressure responsive actuator, these being indicated at 241, 242 and 243. Merely as illustrative, the actuator may include a piston having opposite pressure receiving surfaces 244 and 245 in a chamber 246 to which fluid pressure is supplied by lines 247 and 248, the piston being connected to a gate 249 which functions to block or unblock the upward flow of production through the pipe 234. The two lines 247 and 248 are supplied from a manifold chamber 250 from which other lines 251 and 252 deliver fluid pressure to the valve 236, and lines 253 and 254 deliver pressure to the actuator 243. Fluid pressure is supplied to the manifold chamber 250 by means of a delivery conduit 255 extending downwardly, typically alongside conduit 240 from the surface as from a drilling or producing vessel 256. The manifold chamber 250 may be the same as or similar to that shown at 20, and may contain prime movers and prime mover operated valves such as previously described in FIGS. 6 and 7, with three prime mover operated valves cooperating with the three actuators 241, 242 and 243.

The well completion unit 260 shown in FIG. 9 is the same as that illustrated in FIG. 8 excepting that the well valves 235, 236, and 239 are not operated by fluid pressure responsive actuators, but are operated by the electrically responsive prime movers 261, 262 and 263. These may comprise for example reversible, permanent magnet type electrical motors with suitable mechanism interconnecting the driven shafts of the motors with the respective valves to open and close them or otherwise control them as desired. The numerals 264, 265 and 266 indicate electrical branched conduits extending from a junction box 267 mounted on the upper chamber 233 of the unit 260, a main cable 268 extending downwardly from the surface to the junction box and then branching to the prime movers. The FIG. 9 chamber structure at the well head for receiving fluid may be considered as the well servicing tool and any well valve and its prime mover, as for example valve 235 and prime mover 261, may be considered as electrically responsive means at the sub-surface location for controlling the flow of fluid between the well servicing tool chamber and fluid pressure delivery means as for example the conduit 237, or the conduit 240 delivery mud or other fluid to or from the well interior at 270 outside the pipe 234, as controlled by the well valve 239 and its prime mover 263.

Turning now to the FIG. 10 circuit, it generally illustrates the circuit means, including cable extending below the water surface for electrical connection with the electrically responsive means at the sub-surface location, to control energization thereof thereby controlling the operation of the well completion tool means of FIGS. 8 or 9. Thus, the reversible permanent magnet type motor 271 may be considered usable for any of the motors 261, 262 and 263 of FIG. 9 or any of the motors in the manifold chamber 250 of FIG. 8. Considered on an overall basis the FIG. 10 circuit comprises a pair of like circuit sections generally shown at 272 and 272*a*, each section including a surface portion 273, an underwater cable portion 274 and a sub-surface portion 275 at the well head location. That portion of each circuit section at the surface includes an iron core transformer 276 having primary and secondary coils 277 and 278, coil 277 having end terminals 279 and 280, and coil 278 having end terminals 281 and 282 as well as an intermediate tap or terminal 283. A line connects terminal 279 with the main power line 285 supplying both circuit sections, and a line 286 connects the terminal 281 with the main line 285. A switch 287 is operable to connect either of the lines 284 and 286 to the main line 285. The intermediate tap or terminal 283 of the coil 278 is connected via a line 288 with the main line 285, and another line 289 is run from the terminal 282 of coil 278 to terminal 279 in line 284, there being a filament type indicator light 290 connected in series in the line 289. Finally, terminal 280 is connected through a transmission line 291 in the sub-surface cable generally shown at 292 in FIG. 8 and at 268 in FIG. 9, with the terminal 293 of the motor 271, a rectifier 294 being provided at the surface in the transmission line and a pressure switch 295 being provided at the sub-surface location, typically within the manifold chamber 250 of FIG. 8. The pressure switch functions as previously described at 51 to open the circuit established through the transmission line 291 when the motor 271 has operated within the chamber 250 of FIG. 8 to cause the motor operated valve also within the chamber to transmit fluid pressure to the appropriate well valve actuators.

Considering the stand-by operation of the like pair of circuit sections 272 and 272*a*, it will be observed that a crossover circuit 296 is provided between the switching portions of the circuit sections 272 for preventing simultaneous energization of both sections as by operation of both switches 287 and 287*a*. Also it will be understood that alternate operation of the circuit sections operates the motor 271 forwardly and reversely, thereby to open and close the motor driven valve, as for example any of the well valves in FIG. 9 or any of the prime mover operated valves in the manifold chamber 250 in FIG. 8.

During stand-by operation of each of the circuit sections 272 and 272*a*, the indicator lights 290 and 290*a* glow with less than full brilliance, and the power supplied to the prime mover 271 is less than required to effect operation thereof. In this regard, the rectifiers 294 and 294*a* in the respective circuit sections are arranged mutually oppositely in the transmission lines 291 so that during the positive half of the A.C. cycle current is supplied through the rectifier 294*a* to the motor 271 and thence to the return lines 297, 298 and 299, whereas during the negative half of the cycle current flows from those return lines to the motor 271 and then back through the other circuit section incorporating rectifier 294. Tracing the current flow from rectifier 294, it passes through the coil 277, indicator 290, line 289, coil 278, line 286, switch 287 and then back to the main line 285. During the positive half of the cycle the current passes reversely through these same elements in the circuit section incorporating rectifier 294*a* and indicator 290*a*.

When operation of the motor 271 is desired to close the motor actuated valve, the switch 287*a* at the surface is closed, typically manually. Accordingly, current now flows on the positive half of the cycle through line 284*a*, coil 277*a*, transmission line 291*a* and then to the motor 271 with sufficient power supplied to effect motor operation since there is less effective impedance in the circuit. At the same time, the current passing through the coil 277*a* causes by transformer action a voltage to be produced in the coil 278*a*. The latter voltage then causes a current to flow through the line 289*a* and lines 284*a*, the cross-over circuit 296*a*, main line 285 and line 288*a* back to the tap 283*a* of the coil 278*a*. Under thse conditions the filament lamp 290*a* burns with relatively greater brilliance. Upon motor operation to fully close the valve driven thereby, the switch 295*a* opens in the transmission line 291*a*, breaking the circuit and causing the indicator light 290*a* to go out, whereby the operator may know at a glance that the valve is closed. In this regard, the switch 295*a* may comprise a pressure switch such as that pre-

viously described at **51** when the motor **271** is incorporated in the FIG. 8 manifold chamber **250**. Conversely, the switch **295***a* may comprise a torque switch responsive to increasing torque loading of the motor upon closing of the motor driven valve, as for example would be useful in the FIG. 9 case.

Should the operator now desire to open the valve driven by the motor **271**, he will operate the switch **287***a* to stand-by position shown in FIG. 10 and then close the switch **287** thereby causing the motor **271** to operate reversely until the motor driven valve is opened and the switch **295** opens to break the circuit through the transmission line **291**.

Suitable capacitors are shown at **300** and **300***a* connected respectively between the transmission line **291** and the return line **299** at the surface, and between the transmission line **291***a* and the return line **299** at the surface. Since these capacitors are at the load sides of the rectifiers **294** and **294***a*, they operate to smooth out the ripple current supply to the motor **271**. Also, an emergency D.C. power source is shown at **301** at the surface with a double pole double throw switch **302** having terminals **303** and **304** connected with the transmission line **291** and the return line **299**, and also having terminals **303***a* and **304***a* respectively connected with the transmission line **291***a* and the return line **299**. Accordingly, either circuit section may be energized with direct current by emergency operation of the switch **302** to cause the motor **271** to be driven forwardly or reversely as required.

Summarizing, when the valve operated by the motor **271** is closed, the indicator light **290***a* will be out whereas the indicator light **290** will be on. When the valve is opened, the light **290***a* will be on and the light **290** will be off. At intermediate points between open and closed, both lights **290** and **290***a* will be on.

Referring now to FIG. 11 it incorporates the same circuitry as shown in FIG. 10 with the following differences. The switches **295** and **295***a* comprise pressure or limit switches, and additional torque switches **305** and **305***a* are connected in series with the switches **295** and **295***a* respectively and resistors **306** and **306***a* are connected across the torque switches as shown. Accordingly, the indicator lights **290** and **290***a* will burn dimly when the torque switches **305** and **305***a* are opened as by operation of the motor **271** to cause the valve driven thereby to be fully opened or fully closed as the case may be.

When the motor driven valve is open, switches **295** and **305** will be open. Indicator **290** will be out and **307** will be on. At the same time switches **295***a* and **305***a* will be closed and indicator **290***a* will be on and neon indicator **307***a* will be off. When the motor driven valve is closed switches **295** and **305** will be closed. Indicator **290** will be on and **307** will be off. At the same time switches **295***a* and **305***a* will be open and indicator **290***a* will be off and indicator **307***a* will be on.

When the motor driven valve is between open and closed, switches **295**, **305**, **295***a* and **305***a* will all be closed and indicators **290** and **290***a* will be on and indicators **307** and **307***a* will be off. Thus the operator will at all times be apprised of the condition of the valve whether it is actively open, actively closed or at an intermediate position characterized as inactive or offset from said active positions.

I claim:

1. Apparatus for servicing submarine well head tool means having a pressure responsive actuator comprising delivery means for delivering fluid pressure to said actuator and including supply conduit extending below the water surface to the underwater well head location, electrically responsive means including valving prime mover means and prime mover operated valving at said location for controlling the flow of fluid between said delivery means and said tool means actuator, said prime mover means being electrically energizable, and circuit means including cable extending below the water surface for electrical connection with said electrically responsive means to control energization thereof thereby controlling the operation of said tool means to service the well, said valving having active positions in which fluid pressure is selectively applied to operate the actuator to selected configurations and an inactive position offset from said active positions, said circuit means including circuit sections one for selectively controlling energization of said valving prime mover means to operate the valving to one position, and another for selectively controlling energization of said valving prime mover means to operate the valving to another position, and said sections including means to effect indication at the surface of the condition of said valving as being at either of said active positions or at an inactive position, said fluid pressure delivering means including an underwater fluid pressure manifold chamber for receiving fluid pressure from said conduit, said chamber containing said valving, and said fluid pressure delivering means including porting in said chamber through which fluid may escape from said tool means and through said valving to the sub-surface water.

2. Apparatus for servicing submarine well head tool means having a pressure responsive actuator, comprising delivery means for delivering fluid pressure to said actuator and including supply conduit extending below the water surface to the underwater well head location, electrically responsive means including valving prime mover means and prime mover operated valving at said location for controlling the flow of fluid pressure via said delivery means to said tool means actuator, said prime mover means being electrically energizable, and circuit means including cable extending below the water surface for electrical connection with said electrically responsive means to control energization thereof thereby controlling the operation of said tool means to service the well, said delivery means including a sealed chamber adapted for connection with said tool means, said chamber extending about and forming a vertical through opening to pass equipment being run into the well, said valving contained in said chamber and out of communication with said opening, said fluid pressure delivery means including porting in said chamber through which fluid may escape from said tool means and through said valving to the sub-surface water.

3. Apparatus for servicing submarine well head tool means having a pressure responsive actuator, comprising delivery means for delivering fluid pressure to said actuator and including supply conduit extending below the water surface to the underwater well head location, electrically responsive means including valving prime mover means and prime mover operated valving at said location for controlling the flow of fluid pressure via said delivery means to said tool means actuator, said prime mover means being electrically energizable, and circuit means including cable extending below the water surface for electrical connection with said electrically responsive means to control energization thereof thereby controlling the operation of said tool means to service the well, said valving having different positions in which fluid pressure is selectively applied to operate the tool means to selected configurations, said circuit means including circuit sections one for selectively controlling energization of said valving prime mover means to operate the valving to one position, and another section for selectively controlling energization of said valving prime mover means to operate the valving to another position, said sections including rectifier means to pass rectified A.C. current flowing in one direction through said valving prime mover means and said one section and to pass current flowing in the opposite direction through said valving prime mover means and said other section.

4. Apparatus for servicing submarine well ahead tool means having a pressure responsive actuator, comprising first and second vessels, delivery means for delivering fluid pressure to said actuator and including supply con-

duit extending below the water surface to the underwater well head location, electrically responsive means including valving prime mover means and prime mover operated valving at said location for controlling the flow of fluid pressure via said delivery means to said tool means actuator, said prime mover means being electrically energizable, and circuit means including cable extending below the water surface for electrical connection with said electrically responsive means to control energization thereof thereby controlling the operation of said tool means to service the well, said valving having active positions in which fluid pressure is selectively applied to operate the actuator to selected configurations and an inactive position offset from said active positions, said circuit means including circuit sections one for selectively controlling energizaiton of said valving prime mover means to operate the valving to one position, and another for selectively controlling energization of said valving prime mover means to operate the valving to another position, and said sections including means to effect indication at the surface of the condition of said valving as being at either of said active positions or at an inactive position, said circuit means including dual control switches respectively on said first and second vessels from one of which said supply conduit is suspended, and a well pipe string extending downwardly to the well head from the other vessel.

5. The combination, comprising a string of tools for servicing a submarine well head, the tools having pressure responsive actuators, delivery means for delivering fluid pressure to said actuators and including supply conduit extending underwater to the string, said delivery means including an underwater fluid pressure manifold chamber assembled in said string for receiving fluid pressure from said conduit, said chamber forming a vertical through opening to pass equipment being run into the well, electrically responsive means including valving prime mover means and valving operated thereby in said chamber for controlling application to different tool actuators of fluid pressure supplied via said valving in said manifold chamber, said prime mover means being electrically energizable, and circuit means for electrical connection with said electrically responsive means to control energization thereof thereby controlling selective operation of said tools to service the well, said valving having active positions in which fluid pressure is selectively applied to operate the actuator to selected configurations and an inactive position offset from said active positions, said circuit means including two current supply circuit sections electrically connected with said valving prime mover means, one section for selectively controlling energization of said valving prime mover means to operate the valving to one position, and another section for selectively controlling energization of said valving prime mover means to operate the valving to another position, said sections including means to effect indication at the surface of the condition of said valving as being at either of said active positions or at an inactive position, said sections including surface station power switch means to control current energization of the valving prime mover means for operating the valving between first and second positions corresponding to desired operating configurations of the tool, said two circuit sections including transmission cable extending underwater from the vicinity of the surface to the vicinity of said valving prime mover means, and rectifier means electrically connected with said cable to supply rectified A.C. current in one direction through said valving prime mover means and one section, and to pass current in the opposite direction through said valving prime mover means and the other section, all in such manner that predetermined operation of said respective circuit sections operates the tool to said selected configurations.

6. The invention as defined in claim 5 in which said indication effecting means in each of said two circuit sections includes a sub-surface pressure operated switch operable to open the circuit section in response to predetermined build-up of fluid pressure application to the tool, and an indicator at the surface and responsive to opening of said switch to indicate the existence of said predetermined build-up of fluid pressure application to the tool.

7. The invention as defined in claim 5 in which said indication effecting means in said two circuit sections includes impedance elements through which relatively lesser and greater current flows to said valving prime mover means in first and second positions respectively of said power switch means, said greater current being required to energize the valving prime mover means sufficiently to operate the valving between first and second positions corresponding to desired tool configurations, one impedance element at said surface station for indicating the existence of said relatively lesser and greater current flow in said one direction and another impedance element at said surface station for indicating the existence of said relatively lesser and greater current flow in said opposite direction.

8. The invention as defined in claim 5 in which said fluid pressure delivery means includes an underwater fluid pressure header duct in said chamber and connected in fluid pressure supplying relation with said valving and also in fluid pressure receiving relation with said underwater conduit.

9. The combination, comprising a string of tools for servicing a submarine well head, the tools having pressure responsive actuators, delivery means for delivering fluid pressure to said actuators and including supply conduit extending underwater to the string, said delivery means including an underwater fluid pressure manifold chamber assembled in said string for receiving fluid pressure from said conduit, said chamber forming a vertical through opening to pass equipment being run into the well, electrically responsive means including valving prime mover means and valving operated thereby in said chamber for controlling application to different tool actuators of fluid pressure supplied via said valving in said manifold chamber, said prime mover means being electrically energizable, and circuit means including underwater cable for electrical connection with said electrically responsive means to control energization thereof thereby controlling selective operation of said tools to service the well, said valving having active positions in which fluid pressure is selectively applied to operate the actuator to selected configurations and an inactive position offset from said active positions, said circuit means including two current supply circuit sections electrically connected with said valving prime mover means, one section for selectively controlling energization of said valving prime mover means to operate the valving to one position, and another section for selectively controlling energization of said valving prime mover means to operate the valving to another position, said sections including means to effect indication at the surface of the condition of said valving as being at either of said active positions or at an inactive position, said fluid pressure delivery means including porting in said chamber through which fluid may escape from said tool means and through said valving to the sub-surface water.

10. The invention as defined in claim 8 including underwater check valve means connected in series with said underwater conduit upstream of said header duct to prevent backflow through said conduit, and underwater filter means connected in series with said check valve means and underwater conduit.

11. The invention as defined in claim 5 in which said circuit means includes an A.C. source connected in current supplying relation with said multiple circuit sections, an emergency D.C. source connectible in current supplying relation with said multiple circuit sections, and switch means for disconnecting and connecting said A.C. and

D.C. sources respectively with said circuit sections, said sources being at an above surface station.

12. The combination, comprising a string of tools for servicing a submarine well head, the tools having pressure responsive actuators, delivery means for delivering fluid pressure to said actuators and including supply conduit extending underwater to the string, said delivery means including an underwater fluid pressure manifold chamber assembled in said string for receiving fluid pressure from said conduit, said chamber forming a vertical through opening to pass equipment being run into the well, electrically responsive means including valving prime mover means and valving operated thereby in said chamber for controlling application to different tool actuators of fluid pressure supplied via said valving in said manifold chamber, said prime mover means being electrically energizable, and circuit means including underwater cable for electrical connection with said electrically responsive means to control energization thereof thereby controlling selective operation of said tools to service the well, said valving having active positions in which fluid pressure is selectively applied to operate the actuator to selected configurations and an inactive position offset from said active positions, said circuit means including two current supply circuit sections electrically connected with said valving prime mover means, one section for selectively controlling energization of said valving prime mover means to operate the valving to one position, and another section for selectively controlling energization of said valving prime mover means to operate the valving to another position, said sections including means to effect indication at the surface of the condition of said valving as being at either of said active positions or at an inactive position, first and second vessels at the surface, a first surface control station on the first vessel, said pressure supply conduit being suspended from said first vessel, a second surface control station on the second vessel, said cable having an extension extending between said stations, and a well pipe string extending downwardly from the second vessel to said string of tools.

13. The invention as defined in claim 5 in which said string includes a housing and blow-out preventing well closure structure movable within said housing between open and closed positions in response to application upon said structure of fluid pressure from said manifold chamber as controlled by prime mover operated valving.

14. The invention as defined in claim 5 in which said string includes a mud flow control valve structure movable between open and closed positions in response to application upon said structure of fluid pressure from said manifold chamber as controlled by prime mover operated valving.

15. The invention as defined in claim 5 in which said string includes a housing and pipe slip structure movable within said housing between pipe gripping and pipe releasing positions in response to application upon said structure of fluid pressure from said manifold chamber as controlled by prime mover operated valving.

16. The invention as defined in claim 5 in which said tools comprise well valves and well valve actuators movable to control movement of said well valves.

17. The combination, comprising a string of tools for servicing a submarine well head, the tools having pressure responsive actuators, delivery means for delivering fluid pressure to said actuators and including supply conduit extending underwater to the string, said delivery means including an underwater fluid pressure manifold chamber assembled in said string for receiving fluid pressure from said conduit, said chamber forming a vertical through opening to pass equipment being run into the well, electrically responsive means including valving prime mover means and valving operated thereby in said chamber for controlling application to different tool actuators of fluid pressure supplied via said valving in said manifold chamber, said prime mover means being electrically energizable, and circuit means including underwater cable for electrical connection with said electrically responsive means to control energization thereof thereby controlling selective operation of said tools to service the well, said valving having active positions in which fluid pressure is selectively applied to operate the actuator to selected configurations and an inactive position offset from said active positions, said circuit means including two current supply circuit sections electrically connected with said valving prime mover means, one section for selectively controlling energization of said valving prime mover means to operate the valving to one position, and another section for selectively controlling energization of said valving prime mover means to operate the valving to another position, said sections inlcuding means to effect indication at the surface of the condition of said valving as being at either of said active positions or at an inactive position, said tool means including a well valve operable to control well fluid flow, and said indication effecting means in each of said two circuit sections including a sub-surface switch one of which is operable to open its circuit section in response to operation of said prime mover means acting to open the well valve and the other of which is operable to open its circuit section in response to operation of said prime mover means acting to close the well valve, each circuit section including a surface indicator responsive to opening of said section sub-surface switch to indicate the open or closed condition of the well valve.

18. Apparatus for controlling the flow of well fluid between a submarine well head chamber and a subsurface conduit communicating with said chamber, comprising electrically responsive means including valving prime mover means and prime mover operated valving at the well head and communicating with said conduit, said prime mover means being electrically energizable, and circuit means including cable extending below the water surface for electrical connection with said electrically responsive means to control energization thereof thereby controlling operation of said valving, said valving having active positions in which fluid pressure is selectively applied to operate the actuator to selected configurations and an inactive position offset from said active positions, said circuit means including circuit sections one for selectively controlled energization of said valving prime mover means to operate the valving to one position, and another for selectively controlling energization of said valving prime mover means to operate the valving to another position, and said sections including means to effect indication at the surface of the condition of said valving as being at either of said active positions or at an inactive position, said sections including rectifier means to pass rectified A.C. current flowing in one direction through said valving prime mover means and said one section and to pass current flowing in the opposite direction through said valving prime mover means and said other section.

References Cited by the Examiner

UNITED STATES PATENTS

2,528,898	11/1950	McIllvaine	137—554
2,614,803	10/1952	Wiggins	175—8 X
2,872,940	2/1959	Lewis	137—554
2,970,646	2/1961	Knapp et al.	166—66.5
3,012,510	12/1961	Kusner	251—133
3,047,078	7/1962	Postlewaite	175—7
3,064,735	11/1962	Bauer et al.	166—66.5

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