MODULAR ACTUATOR FOR SUBSEA VALVES AND EQUIPMENT, AND METHODS OF USING SAME

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

The present invention is generally directed to the field of actuators, and more particularly to a modular actuator for subsea valves and equipment, and various methods of using same. In one illustrative example, the present invention is directed to a system for controlling an actuator for a downhole safety valve in a subsea Christmas tree.

2. DESCRIPTION OF THE RELATED ART

The production from a subsea well is controlled by a number of valves that are assembled into a Christmas tree. The actuation of the valves is normally dependent upon hydraulic fluid to operate hydraulic actuators for the valves and is therefore entirely dependent upon an external source for the supply of pressurized hydraulic fluid. Hydraulic power is normally supplied through an umbilical running from a station located on a vessel on the surface or, less common, from a land based station. Usually the actuators are controlled by pilot valves housed in a control module located at or near the subsea installation, the pilot valves directing the supply of hydraulic fluid to each actuator, as dictated by the need for operation. The pilot valves may be operated by electric means and such a system is therefore called an electro-hydraulic system.

The design of actuators and valves for subsea wells are dictated by stringent demands on the standard and function for these valves, because of the dangers of uncontrolled release of hydrocarbons. A typical demand is that these valves must be failsafe closed, meaning that they must close upon loss of power or control. The only practical means today in subsea

environments is to use springs that are held in the compressed state by the hydraulic pressure, keeping the valve open, and will be released in the event of loss of hydraulic pressure, thus closing the valve. The spring force needed to close a valve is dependent upon both well pressure and ambient pressure, with larger ambient pressure demanding larger springs.

For the control of subsea wells, a connection between the well and a monitoring and control station must be established. This station can either be located in a floating vessel near the subsea installations or in a land station a long distance away. Communication between the control station and the subsea installation is normally provided by installing an umbilical between the two points. The umbilical contains lines for the supply of hydraulic fluid to the various actuators in or by the well, electric lines for the supply of electric power and signals to various monitoring and control devices and lines for signals to pass to and from the well. This umbilical is a very complicated and expensive item, costing several thousand dollars per meter.

It would therefore be very cost-saving to be able to eliminate the umbilical. Proposals have been made to use electrically operated actuators for subsea valves instead of the traditional hydraulic actuators, see for example U.S. Patent Nos. 5,497,672 and 5,984,260. However, this entails the installation of completely new actuators, resulting that it is not possible to retrofit a hydraulic system with an electric actuator.

EP Patent Application No. 1209294 discloses an electro-hydraulic control unit with a piston/cylinder arrangement with the piston dividing the cylinder into two chambers, a fluid connection between the two chambers and a valve to configure the fluid flow such that pressurized hydraulic fluid only may flow in one direction, but not in both directions.

U.S. Patent No. 6,269,874 discloses an electro-hydraulic surface controlled subsurface safety valve actuator that comprises an electrically actuated pressure pump and a dump valve that is normally open so that if power fails, the pressure is released and the safety valve closes.

The present invention is directed to an apparatus for solving, or at least reducing the effects of, some or all of the aforementioned problems.

SUMMARY OF THE INVENTION

The present invention is directed to a modular actuator for subsea valves and equipment, and various methods of using same. In one illustrative embodiment, the actuator comprises a hydraulic actuator, at least one housing and a self-contained hydraulic supply system positioned within the at least one housing.

In another illustrative embodiment, the actuator comprises a hydraulic actuator, at least one housing and a plurality of components positioned within the at least one housing, the components comprising a self-contained hydraulic supply system and a control system to control delivery of a high pressure hydraulic fluid produced by the self-contained hydraulic supply system.

In yet another illustrative embodiment, the actuator comprises a hydraulic actuator, at least one housing and a self-contained hydraulic supply system positioned within the at least one housing, the self-contained hydraulic supply system comprising a pump driven by an electrical motor, at least one fluid reservoir and a control/vent valve.

In a further illustrative embodiment, the actuator comprises a hydraulic actuator, at least one housing and a self-contained hydraulic supply system positioned within the at least one housing, the self-contained hydraulic supply system comprising a pump driven by an electrical motor, at least one fluid reservoir and a control/vent valve. The actuator further comprises a

control system positioned within the at least one housing to control delivery of a high pressure hydraulic fluid produced by the self-contained hydraulic supply system and a self-contained source of electrical power positioned within the at least one housing, wherein the self-contained source of electrical power is the primary source of electrical power for the modular actuator.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may be understood by reference to the following description taken in conjunction with the accompanying drawings, in which like reference numerals identify like elements, and in which:

Figure 1 is a schematic depiction of one illustrative embodiment of the present invention employed in connection with a subsea valve;

Figure 2 is another schematic depiction of an alternative embodiment of the present invention employed in connection with a subsea equipment item;

Figures 3a-3f describe various aspects of a modular actuator in accordance with one illustrative embodiment of the present invention;

Figure 4 is a schematic depiction of an illustrative modular actuator in accordance with one embodiment of the present invention;

Figure 5 is a depiction of yet another illustrative embodiment of a modular actuator in accordance with the present invention;

Figure 6 is a more detailed schematic depiction of one illustrative embodiment of the present invention in a first working mode;

Figure 7 is a detailed schematic depiction showing one illustrative embodiment of the present invention in a fail safe mode;

Figure 8 is yet another illustrative embodiment of the present invention employing an alternative valve arrangement; and

Figures 9a-9c depict an illustrative embodiment of the present invention in various operating configurations.

While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the description herein of specific embodiments is not intended to limit the invention to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE INVENTION

Illustrative embodiments of the invention are described below. In the interest of clarity, not all features of an actual implementation are described in this specification. It will of course be appreciated that in the development of any such actual embodiment, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort might be complex and time-consuming, but would nevertheless be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure.

The present invention will now be described with reference to the attached figures. The words and phrases used herein should be understood and interpreted to have a meaning consistent with the understanding of those words and phrases by those skilled in the relevant art. No special definition of a term or phrase, *i.e.*, a definition that is different from the

ordinary and customary meaning as understood by those skilled in the art, is intended to be implied by consistent usage of the term or phrase herein. To the extent that a term or phrase is intended to have a special meaning, *i.e.*, a meaning other than that understood by skilled artisans, such a special definition will be expressly set forth in the specification in a definitional manner that directly and unequivocally provides the special definition for the term or phrase.

In the following description, the term fluid line is used to indicate a fluid connection between components of the system. It should be understood that in various embodiments, the fluid connection between components may comprise an actual fluid conduit such as a pipe or hose, or the components may be connected directly to each other. Any configuration which allows for fluid communication between components as described below is considered to be within the spirit and scope of the invention.

In the specification, terms such as "upward" or "downward" or the like may be used to refer to the direction of fluid flow between various components of the devices depicted in the attached drawings. However, as will be recognized by those skilled in the art after a complete reading of the present application, the device and systems described herein may be positioned in any desired orientation. Thus, the reference to the direction of fluid flow should be understood to represent a relative direction of flow and not an absolute direction of flow. Similarly, the use of terms such as "above," "below," or other like terms to describe a spatial relationship between various components should be understood to describe a relative relationship between the components as the device described herein may be oriented in any desired position.

Also in the following description, the terms low pressure and high pressure are used to describe various portions of the system. It should be understood that these terms are used in a relative sense. Low pressure is used to describe the fluid supply and the portions of the system

in fluid communication with the fluid supply. High pressure is used to describe the fluid which is pressurized by the pump or other pressure intensifying device, and the portions of the system in fluid communication with pump output. The term high pressure is used only to indicate that this portion of the system is at a higher pressure relative to the fluid supply. The term low pressure is used only to indicate that this portion of the system is at a lower pressure than the pump output. The actual absolute or gauge pressure of the various portions of the system is irrelevant to the definition of high or low pressure.

Figures 1 and 2 schematically depict illustrative systems 10 employing a modular actuator 16 in accordance with various aspects of the present invention. As depicted in Figure 1, the modular actuator 16 is operatively coupled to a valve actuator 15 that is operatively coupled to a subsea valve 12 positioned in a flow line or well conduit 14. The valve actuator 15 may be of any type, *e.g.*, a mechanical valve actuator, a hydraulic valve actuator, etc. Thus, the particular type of valve actuator disclosed herein should not be considered a limitation of the present invention. In the embodiment depicted in Figure 2, a plurality of modular actuators 16 are operatively coupled to valve actuators 15 that, in turn, are operatively coupled to a item of subsea equipment 18, such as an illustrative Christmas tree. As will be described more fully below, in one illustrative embodiment, the modular actuator 16 of the present invention is a self-contained actuator that is adapted to actuate a subsea valve 12 or other similar type component. In the illustrative embodiment depicted in Figure 2, the plurality of modular actuators 16 are adapted to control a plurality of valves (not shown) positioned internally within the schematically depicted Christmas tree 18.

As will be described more fully below, the modular actuator 16 described herein comprises a self-contained power supply, and it may be readily decoupled from the valve actuator 15 and removed to the surface. Importantly, in one illustrative embodiment, the

modular actuator 16 described herein comprises a self-contained hydraulic system that will be used, at least in part, to actuate the subsea valve 12 or other like equipment. In accordance with one illustrative aspect of the present invention, since the modular actuators 16 described herein employ a self-contained hydraulic system, a supply of high pressure hydraulic fluid from a station location on a surface vessel or from a land-based station is not required. Moreover, the modular actuator 16 disclosed herein is configured so that it may be easily coupled and decoupled from the subsea equipment, *e.g.*, the valve actuator 15, to which it is attached by a variety of techniques, *e.g.*, by use of an ROV (remotely operated vehicle), a diver, etc., and retrieved to the surface as necessary for repairs.

Figures 3a-3f depict one illustrative embodiment of the modular actuator 16 in accordance with the present invention. In general, the modular actuator 16 comprises a hydraulic actuator and one or more housing portions that are adapted to contain various components of the modular actuator 16, including a self-contained hydraulic supply system. As depicted in Figures 3a-3f, the modular actuator 16 comprises a linear override tool 16A and housings 16B, 16C, 16D for housing various electrical and hydraulic components, including hydraulic fluid, associated with the modular actuator 16. Although the illustrative embodiment depicted herein comprises three separate housings 16B, 16C, 16D, those skilled in the art, with the benefit of the present disclosure, will understand that the modular actuator 16 may comprise one or more housings to house the various components of the system described herein. Thus, the present invention should not be considered as limited to the illustrative embodiments depicted herein.

In the depicted embodiment, an interface device 17 may be provided between the modular actuator 16 and the valve actuator 15. Even more specifically, in the illustrative example depicted herein, the interface device 17 may comprise a spool having a first flange

17A, a second flange 17B and a travel indicator 17C. The first flange 17A is adapted to be coupled to the valve actuator 15. Typically, the interface device 17 may be coupled to the valve actuator 15 at the time the subsea system is placed into service. Thereafter, the modular actuator 16 may be operatively coupled to the flange 17B when desired or needed, as will be described more fully below. As will be recognized by those skilled in the art after a complete reading of the present application, the interface device 17 may take a variety of shapes and forms. For example, in one illustrative embodiment, the interface device 17 may be designed in accordance with the teachings of a standard entitled "Design and Operation of Subsea Production Equipment Systems," ISO/FDIS 13628-8:2000(E), pp. 39-42. In other embodiments, a separate interface device 17 need not be provided. That is, to the extent an interface is provided, it may be provided as an integral part of either the valve actuator 15 or the modular actuator 16.

As to more specifics, the modular actuator 16 may comprise a hydraulic fluid reservoir 16D, an ROV handle 16E, an ROV handle 16F, a shaft 16G and a plurality of seals 16H. The modular actuator 16 is provided with a recess 16I that is adapted to be positioned around the flange 17B of the interface device 17. A plurality of anti-rotation devices 16J, *e.g.*, studs or nuts, are provided to reduce or prevent rotation of the modular actuator 16 relative to the interface device 17.

Figures 3a-3c depict the modular actuator 16 as it is being lowered onto the flange 17B of the interface device 17. An ROV may be used to install the modular actuator 16. As indicated previously, in one illustrative embodiment, the interface device 17 is attached to the valve actuator 15 as part of the initial installation process of the subsea system. Any number of valves of a particular subsea system may be provided with such an interface device 17 such that a modular actuator 16 may be operatively coupled to such valves when needed. More

specifically, in one illustrative embodiment, an ROV (remotely operated vehicle) or other like device may be employed to position the modular actuator 16 in a position where it may operate a subsea devices, such as a valve. The modular actuator 16 may be lowered onto the flange 17B through use of an ROV that grasps ROV handle 16E. Figure 3c depicts the modular actuator 16 in the fully landed position. The recess 16I is sized such that the modular actuator 16 fits securely around the flange 17B. The anti-rotation devices 16J prevent or reduce rotation of the modular actuator 16 relative to the interface device 17 and the valve actuator 15. When the modular actuator 16 is in a horizontal position, the weight of the modular actuator 16, along with the closeness of fit between the recess 16I and the flange 17B, tend to secure the modular actuator 16 in position. With reference to Figure 3E, when the modular actuator 16 is activated or stroked, the shaft 16G will extend into the bore of the interface device 17 thereby insuring that the modular actuator 16 remains in place irrespective of whether the valve actuator 15 is positioned horizontally, vertically, or at any other angle. Additional operational aspects of the modular actuator 16 will be described more fully below.

Illustrative examples of the associated electrical and hydraulic controls that may be employed with the modular actuator 16 are depicted in Figure 3f. As shown therein, the system comprises an accumulator 16K, a pump 16L, driven by an electric motor 16M, a check valve 16N, pressure sensors 16O, 16P, 16Q, a filter 16R and a solenoid valve with spring return 16S. In one illustrative embodiment, the solenoid valve 16S may be a normally closed valve, as depicted in Figure 3f. When the solenoid valve 16S is actuated and moved to its "open" position, the pump 16L may be activated to increase the pressure of the hydraulic fluid supplied to the chamber 16T. In turn, this causes the shaft 16G to move to the right in Figure 3f, as indicated by the arrow 16U. The end 16W of the shaft 16G engages the end 15B of the shaft 15A (see Figure 3e) of the valve actuator 15 when the shaft 16G moves in the direction of

the arrow 16U. The pump 16L continues to operate until the pressure on both sides of the solenoid valve 16S is substantially equal, as determined by the pressure sensors 16P, 16Q. At that point, the shaft 16G is fully extended and the pump 16L may be stopped.

When the solenoid valve 16S is de-energized, *e.g.*, in an emergency situation, the solenoid valve 16S returns (due to its spring return) to its closed position, as depicted in Figure 3f. With the solenoid valve 16S in the closed position, the high pressure hydraulic fluid in the chamber 16T is free to return to the accumulator 16K, and the shaft 16G is free to travel to the left in Figure 3f, as indicated by the arrow 16V, until it reaches its fully retracted position. A force, such as a spring force, may be supplied to urge the shaft 16G to its fully retracted position. Such a force may be supplied by, for example, a return spring on a subsea safety valve. A portion of the shaft 16G will remain positioned within the bore of the interface device 17 even when the solenoid valve 16S is in its closed position (as shown in Figure 3f). In one embodiment, to fully retract the shaft 16G from inside the bore of the interface device 17, an ROV is employed to grasp and pull on the handle 16F (see Figure 3e). Once the shaft 16G has been complete disengaged from the bore of the interface device 17, the modular actuator 16 may be removed by use of an ROV that grasps the handle 16E. An ROV may be used to open or close a needle valve 16Y (see Figure 3F), via handle 16X (see Figure 3e), to vent the system if the need arises. A travel indicator 17C may be used to determine the movement of the shaft 15A. The travel indicator 17C is secured to the shaft 15A by a bolt 17D (see Figure 3e). The bolt 17D is free to travel within the groove 17E.

Figure 4 is a schematic depiction of the various components that may be included in one illustrative embodiment of the modular actuator 16 disclosed herein. As shown in Figure 4, a variety of components are positioned in a one or more housings, generally indicated by the number 20, associated with the modular actuator 16. The exact number of housings and the

location of various components of the system described herein may vary depending upon the particular application. Of course, the modular actuator 16 will ultimately b e operatively coupled to an illustrative valve actuator 15. In general, the modular actuator 16 comprises, in one illustrative embodiment, a fluid reservoir-accumulator 44, a pressure intensifier 47, a check valve 34, a control/vent solenoid valve 40, a battery 54 and a control system 50. A plurality of hydraulic flow lines 45, 36, 48 and 42 are positioned within the housing 20. The modular actuator 16 further comprises an illustrative electrical connection 36 that is adapted to mate with a schematically depicted electrical line 37.

The pressure intensifier 47 schematically depicted in Figure 4 may be comprised of a variety of devices. The pressure intensifier 47 may be any device or system that employs electrical power to increase the pressure in a fluid. For example, in one embodiment, the pressure intensifier 47 may be a rotary pump driven by a schematically depicted electric motor 31 shown in Figure 4. In another illustrative embodiment, the pressure intensifier 47 may also be a reciprocating pump driven by an electric motor (see, *e.g.*, Figures 9a-9c). In the illustrative embodiment depicted in Figure 4, the system within the modular actuator 16 is adapted to provide a high pressure hydraulic fluid to a component, such as the illustrative subsea valve 12, to accomplish the desired purpose, *e.g.*, to move a valve from a first position to a second position.

Electrical power for the electrical components within the housing 20 may be provide by an electrical line that extends to a surface source of electrical power or it may be provided by one or more batteries that are positioned inside the housing 20 or otherwise located proximate to the modular actuator 16. Moreover, depending upon the particular application the batteries may be the primary source of electrical power for the electrical components within the housing 20. In one illustrative embodiment, the battery 54 (see Figure 4) is positioned in the housing

20 and it is the primary source of power for the electrical components of the modular actuator 16, e.g., the motor 31, the control system 35, the solenoid control/vent valve 40, etc. Thus, in this embodiment, the modular actuator 16 also has a self-contained electrical power source. The battery 54 (or groups thereof) may be any of a variety of commercially available batteries employed in subsea applications.

Recharging the battery 54 may be accomplished by a substantially continuous trickle charge that is applied to the battery 54. Alternatively, the control system 35 may be employed to monitor the stored charge in the battery 54 and when it reaches a certain minimum allowed level, the battery 54 may be recharged by temporarily coupling it to a full power electrical line. In other embodiments, electrical power to the electrical components with the housing 20 may be provide by a traditional electrical power line or cable and the battery 54, if present, may serve a traditional back-up role.

If it is desired to replace the battery 54 within the housing 20 of the modular actuator 16, then the modular actuator may be decoupled from the subsea valve 12 or equipment 18 and taken to the surface. As described previously, an ROV or diver may be employed to decouple the modular actuator 16 from the subsea valve 12 or equipment 18 and transport it to the surface.

The illustrative control system 50 depicted within the modular actuator 16 is adapted to sense various conditions existing within the system contained in the modular actuator 16 and take various control actions in response thereto, as described more fully below. The control system 35 may take a variety of shapes and forms. In one illustrative embodiment, the control system 50 comprises a programmable logic device or a microprocessor and a memory device for storing a variety of data and/or programs.

Figure 5 depicts yet another illustrative embodiment of the modular actuator 16 described herein. Relative to the embodiment depicted in Figure 4, in the embodiment depicted in Figure 5, a hydraulic actuator 28 (having a shaft or stem 21 and an end interface 27) has been included in the modular actuator 16. In this illustrative embodiment the interface 27 of the hydraulic cylinder 28 may be coupled to any of a variety of devices, *e.g.*, a subsea valve, and actuated to open or close such a valve.

Figure 6 is a more detailed depiction of some of the various components of the modular actuator 16 in accordance with one illustrative embodiment of the present invention. For ease of reference many of the components shown in Figures 1-5 will be shown in Figures 6-8 with a corresponding "1" prefix. As shown therein, an actuator 128 has a cylindrical housing 112. A piston 114 is axially movable in the housing, between first and second positions. A stem 121 is attached to the piston 114 and extends outside the housing 112. An illustrative flange or bracket 122 is provided for operatively coupling the actuator 129 to a subsea valve (not shown in Figure 6). In one illustrative embodiment, the actuator 129 is provided with a handle 124 that enables the actuator 129 to be transported and mounted with an ROV. A linear override tool 120 may also be used for manually moving the piston 114, using an ROV tool. The actuator 129 depicted in Figure 6 may be employed with a modular actuator 16 like the one schematically depicted in Figure 4. Of course, the actuator 129 depicted in Figure 6 may also be employed with a modular actuator 16 like the one schematically depicted in Figure 5, wherein the actuator 129 is positioned within the housing 20 of the modular actuator 16. Of course, in that case, the actuator 129 may not be provided with a separate ROV handle 124 or the linear override tool 120.

The piston 114 includes seals 111 to seal the piston 114 against the cylinder. The piston 114 defines first 113 and second 115 (see Figure 7) chambers in the housing 112. A

fluid line 142 connects the second chamber 115 with a variable volume fluid reservoir-accumulator 144. In one illustrative embodiment, the fluid in accumulator 144 is at ambient sea pressure. The variable volume accumulator 144 evens out pressure surges in the return system and also provides for spare fluid capacity, as is well known in the art. A fluid line 145 connects the accumulator 144 with the intake side of an illustrative pressure intensifier, e.g., a pump 147. A stub fluid line with a coupling 143 can be incorporated into the fluid line 145, to enable fluid to be replenished and refill the accumulator 144. A fluid line 136 connects the first chamber 113 with the pressure side of pump 147. A one-way valve or check valve 134 is installed in fluid line 136, allowing fluid to flow only towards chamber 113.

An additional fluid line 148 interconnects fluid lines 145 and 136. In fluid line 148 there is mounted a control-vent solenoid valve 140, the valve 140 being movable between a closed position (Figure 7) preventing fluid flow through line 148, and an open position (Figure 8) allowing fluid flow through line 148. As seen from Figure 8, when valve 140 is in its open position fluid may flow in either direction between the first chamber 113 and the second chamber 115. A spring 139 is arranged to bias the valve 140 towards its open position. A solenoid 138 may be selectively energized to move the valve 140 to its closed position, against the biasing force of the spring 139.

The pump 147 is operated by a motor 131. Pressure and temperature sensors 127 and 133 are mounted in fluid lines 136 and 145, respectively. A filter unit 146 may be installed in fluid line 145 between the pump intake and the fluid supply 144.

The various parts of the unit are in communication with a control module 150 through cables 126, 128, 130 and 132. The control module 150 is in communication with a remote station (not shown) via a cable 152, to receive power and communication signals therefrom.

In one illustrative embodiment, the motor 131 is a brushless DC motor. Also, in one illustrative embodiment, the control module 150 includes a battery 154 to provide primary power to the motor 131 and the solenoid 138. The battery 154 may be trickle-charged from a local power source or from a remote location. In this instance, only a small cable would be needed to charge the battery 154. Alternatively, primary electrical power may be supplied from a remote location and the battery 154, if present, may merely serve as a traditional back-up source for an emergency supply of electrical power.

Figure 7 depicts the present invention in a fail safe mode. As shown therein, a subsea valve 212 is adapted to be operated by the actuator 129. The valve 212 comprises a valve element 202 connected to a valve stem 204, the valve stem 204 extending into and through a spring housing 206. A spring 208 is located in the spring housing 206. The valve stem 204 has a spring actuating flange 210 rigidly attached thereto. The valve stem 204 terminates in a standard interface mechanism 211. The piston stem 121 has at its end a corresponding interface 127, allowing the valve stem 204 to be operably connected to the piston stem 121.

In Figure 7, the valve element 202 is depicted in the closed position. To move the valve element 202 to its open position, the solenoid 138 is energized to move the two-way valve 140 to the closed position shown in Figure 7, against the force of the spring 129. This closes the fluid path between chambers 113 and 115 of the actuator 128. Then the motor 131 is operated to drive the pump 147, thus transferring fluid from the low pressure portion of the system (comprising the second chamber 115 and the accumulator 144) to the first chamber 113 of the actuator 129. The high pressure fluid in chamber 113 displaces the piston 114 to its second (extended) position, shown in Figure 8.

Consequently, this will move the valve stem 204, causing the valve element 202 to move to its open position (not shown in Figure 7). Pressure sensor 127 senses the pressure in

fluid line 136, and the control module 150 cuts power to the motor 131 when the pressure in line 136 is sufficient to drive the valve stem 206 against the power of the spring 208. One-way valve 134 and two-way-valve 140 prevent high pressure fluid from exiting chamber 113, thus ensuring that the valve element 202 is held in its open position. In moving the valve element 202 to its open position, the spring 208 is compressed thereby creating a bias return force in the spring 208 that will tend to move the valve element 202 to its closed position.

When it becomes necessary to close the valve 202, either electively or in an emergency situation, power to the solenoid 138 is shut off, causing the two-way valve 140 to move to its open position shown in Figure 8 as a result of the biasing force provided by the spring 139. This opens the fluid communication path between first 113 and second 115 chambers, and blocks or shuts off flow from the pump 147 to the first chamber 113. Since the pressure now is equalized on each side of the piston 114, the spring 208 will force the piston 114 and stem 116 backwards to its first (retracted) position, and the valve 202 will close as fluid is transferred to chamber 115 from chamber 113.

Figure 8 shows a system similar in many respects to the system of Figure 6. However, in Figure 8, a flow line 167 extends between chamber 113 of the actuator 129, and a first port of a three-way solenoid valve 160. A second port of valve 160 is connected to flow line 136, which is in turn connected to the output of pump 147. A third port of valve 160 is connected to flow line 168, which is in turn connected to flow line 145. The valve 160 is biased towards a first, or venting position (not shown) by a spring 161. A solenoid 162 is selectively operable to move valve 160 to a second position, as shown in Figure 8. In the second position, the valve 160 allows fluid communication between the output of pump 147 and the first chamber 113. In this position, flow line 168 is blocked. High pressure fluid from the pump 147 is introduced

into the chamber 113 of the actuator 128, thus driving the stem 121 to its extended position which opens the valve element 202.

When it becomes necessary to close the valve 202, either electively or in an emergency situation, power to the solenoid 162 is shut off, causing the three-way valve 160 to move to its first, or venting position. This opens the fluid communication path between first 113 and second 115 chambers, and blocks flow from the pump to the first chamber 113. Since the pressure now is equalized on each side of the piston 114, the spring 208 will force the piston 114 and stem 121 backwards to its first (retracted) position, and the valve 202 will close as fluid is transferred to chamber 115 from chamber 113.

The solenoid valve 160 is pressure-balanced, as will be clearly understood from Figure 8. The required biasing force of the spring 161 is very small, and thus the required holding force of the solenoid 162 may be correspondingly small.

The modular actuator 16 according to the present invention may be made very small and compact. It is releasably connected to the valve 212 making it easy to replace or retrieve for repairs or maintenance. The hydraulic portion of the system is entirely self-contained within the housing 20 of the modular actuator 16. Thus, no external hydraulic lines are necessary – control signals and power are transmitted through a simple and inexpensive electrical cable arrangement. The modular nature of the actuator 16 also makes it possible to exchange the actuator 16 with other types of actuators, such as an all-electric actuator. It is also possible to retrofit the actuator 16 onto a valve which was previously manually operated. Once the valve 212 has been fully actuated, the actuator 16 of the present invention requires very little power to hold the valve in position.

Another exemplary embodiment of a modular actuator 16 in accordance with the present invention is shown schematically in Figures 9a-9c. A hydraulic power unit (HPU) 380

is positioned within the housing 20 of the modular actuator 16. For convenience, the illustrative control system 50 and battery 54 are not depicted in Figures 9a-9c. The unit 380 includes a master cylinder 381 with a piston 382 reciprocally movable axially in the cylinder, thus dividing the cylinder into two chambers 383 and 384. The two chambers 383 and 384 are interconnected through a bypass line 391, the flow through the bypass being controlled by a bypass control valve 390.

In the exemplary embodiment the actuator that moves piston 382 may consist of an electric motor with a gearbox and transmission. In the exemplary embodiment, an electric motor 385 is operatively connected to a shaft 386 by a suitable gearbox 375, such that operation of motor 385 may precisely control the motion of piston 382. Examples of a suitable motor 385 and gearbox 375 combination include a Model Number TPM 050 sold by the German company Wittenstein. The motor may alternatively be a linear electric motor.

In the well tubing there is mounted a controllable downhole safety valve 346, known in the art as an SCSSV (Surface Controlled Subsurface Safety Valve). As is well known in the art, the SCSSV includes a hydraulic cylinder including a "slave" chamber 393. To actuate the SCSSV, chamber 393 is pressurized, pushing a piston 394 against the biasing force of a spring 395 to open the valve 346. A fluid line 387 is connected between the slave chamber 393 with an outlet port 398 of an operation control valve 388 positioned within the housing 20. A first inlet port 396 of operation control valve 388 is connected to fluid line 389, which is connected to cylinder chamber 383. This arrangement controls the flow of fluid from master cylinder 381 to the SCSSV actuator 374. A check valve 399 is mounted in line 389, between the operation control valve 388 and the chamber 383. The check valve 399 allows fluid to flow from chamber 383 to chamber 393, but not the reverse.

An accumulator 400, containing a supply of hydraulic fluid, is connected to the fluid line 387 via line 401, at a point between operation control valve 388 and check valve 399. The accumulator 400 provides a buffer for the high pressure hydraulic fluid, and ensures that the SCSSV will stay open under normal operating conditions.

A pressure balanced compensator 405 is connected to a second inlet port 397 of operation control valve 388 via line 406. A fluid line 408 connects compensator 405 with chamber 384 of master cylinder 381. A fluid line 409 connects compensator 405 with a hydraulic coupling 411. The coupling 411 allows hydraulic fluid to be supplied from an external source (not shown) so that fluid can be added to the hydraulic system.

Referring to Figure 9a, when the motor 385 is energized, the piston 382 will move downward in the master cylinder 381. This forces high-pressure fluid through the line 387 to the slave cylinder 393 in the downhole valve actuator 374, with the operation control valve 388 in a first or open position. On the downstroke, the chamber 384 of master cylinder 381 is refilled from compensator 405. Check valve 399 and accumulator 400 cooperate to maintain the pressure in the line 387 at a level that will hold the SCSSV valve open. Referring to Figure 9b, to close the SCSSV valve, the operation control valve 388 is shifted to its second or closed position. In the second position, operation control valve 388 allows fluid to flow back up through line 387, through line 406 and back into compensator 405. In other words, the slave chamber 393 of the downhole actuator is vented through operation control valve 388 to the low-pressure system.

The pressure differential across piston 382 will normally force the piston back to its upper starting position when the motor is de-energized. However, under certain conditions it may be necessary to reset the piston 382 to the upper position. To do this, bypass control valve 390 is shifted to a second, or open position, as shown in Figure 9c. In the second position,

bypass control valve 390 allows fluid to flow through the bypass line between the two chambers 383 and 384 of the master cylinder. The electric motor 385 may then be run in reverse in order to move the piston 12 back to the upper starting position.

Referring to Figure 9b, when it is desired to recharge the accumulator 400, the operation control valve 388 may or may not be shifted to its second position and the motor 385 is energized to drive the piston 382 downward in master cylinder 381. A pressure sensor 413 in line 401 monitors the pressure in the accumulator 400, making it possible to stop the motor 385 when desired pressure is reached.

From time to time it may become necessary to replenish the hydraulic fluid in the system, to replace fluid lost due to leaks, for example. To accomplish this, an external source (not shown) of hydraulic fluid may be coupled to the hydraulic coupler 411. Fluid from the external source fills the compensator 405 and first chamber 384 of master cylinder 381. By shifting the bypass control valve 390 to its open position (Figure 9c), fluid may also flow into second chamber 383. Bypass control valve 390 may then be moved to the closed position (Figure 9b), and piston 382 may be moved downwards to recharge the accumulator 400, as previously described.

The exemplary embodiment of the invention shown in Figures 9a-9c includes a high-pressure section, including accumulator 400, which is maintained at a pressure which is sufficient to operate the SCSSV. This embodiment also includes a low-pressure section, including compensator 405, which is maintained at a second pressure which is less than the pressure required to operate the SCSSV. The compensator 405 may be partly filled with an inert gas such as nitrogen, which compensates for pressure differences due to operation of the SCSSV, and which also primes the system for use at various water depths.

By utilizing the exemplary embodiment of the modular actuator 16 shown in Figures 9a-9c, a standard, hydraulically actuated downhole safety-valve can be used while eliminating the need for a high-pressure hydraulic fluid supply from the surface. Standard downhole safety valves have a spring failsafe feature so that the valve will close when pressure is relieved in the system. The valve will therefore also close in the event of a hydraulic system failure. In an emergency the SCSSV can quickly be closed by shifting operation control valve 388 to its second position, thus venting the high-pressure fluid from line 387.

The present invention is directed to a modular actuator for subsea valves and equipment, and various methods of using same. In one illustrative embodiment, the actuator comprises a hydraulic actuator, at least one housing and a self-contained hydraulic supply system positioned within the at least one housing.

In another illustrative embodiment, the actuator comprises a hydraulic actuator, at least one housing and a plurality of components positioned within the at least one housing, the components comprising a self-contained hydraulic supply system and a control system to control delivery of a high pressure hydraulic fluid produced by the self-contained hydraulic supply system.

In yet another illustrative embodiment, the actuator comprises a hydraulic actuator, at least one housing and a self-contained hydraulic supply system positioned within the at least one housing, the self-contained hydraulic supply system comprising a pump driven by an electrical motor, at least one fluid reservoir and a control/vent valve.

In a further illustrative embodiment, the actuator comprises a hydraulic actuator, at least one housing and a self-contained hydraulic supply system positioned within the at least one housing, the self-contained hydraulic supply system comprising a pump driven by an electrical motor, at least one fluid reservoir and a control/vent valve. The actuator further comprises a

control system positioned within the at least one housing to control delivery of a high pressure hydraulic fluid produced by the self-contained hydraulic supply system and a self-contained source of electrical power positioned within the at least one housing, wherein the self-contained source of electrical power is the primary source of electrical power for the modular actuator.

The particular embodiments disclosed above are illustrative only, as the invention may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. For example, the process steps set forth above may be performed in a different order. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular embodiments disclosed above may be altered or modified and all such variations are considered within the scope and spirit of the invention. Accordingly, the protection sought herein is as set forth in the claims below.

CLAIMS

WHAT IS CLAIMED:

1. A modular actuator adapted to be releasably coupled to a subsea device, comprising:

a hydraulic actuator;

at least one housing; and

a self-contained hydraulic supply system positioned within said at least one housing.

2. The modular actuator of claim 1, further comprising a self-contained source of electrical power positioned within said at least one housing, wherein said self-contained source of electrical power is the primary source of electrical power for said modular actuator.

3. The modular actuator of claim 2, wherein said self-contained source of electrical power comprises at least one battery.

4. The modular actuator of claim 2, further comprising a control system positioned within said at least one housing to control delivery of a high pressure hydraulic fluid produced by said self-contained hydraulic supply system.

5. The modular actuator of claim 1, wherein said self-contained hydraulic supply system comprises a pressure intensifier.

6. The modular actuator of claim 1, wherein said self-contained hydraulic system positioned within said housing comprises a pump driven by an electrical motor.

7. The modular actuator of claim 1, wherein said self-contained hydraulic system comprises at least one fluid reservoir and a control/vent valve.

8. The modular actuator of claim 1, wherein said modular actuator further comprises means for releasably coupling said modular actuator to said subsea device.

9. The modular actuator of claim 4, wherein said self-contained hydraulic supply system is adapted to supply a pressurized fluid employed in actuating a subsea valve.

10. The modular actuator of claim 8, wherein said modular actuator is adapted to be releasably coupled to said subsea device by an ROV.

11. A modular actuator adapted to be releasably coupled to a subsea device, comprising:

a hydraulic actuator;

at least one housing;

a self-contained hydraulic supply system positioned within said at least one housing, said self-contained hydraulic supply system comprising:

a pump driven by an electrical motor;

at least one fluid reservoir; and

a control/vent valve;

a control system positioned within said at least one housing to control delivery of a high pressure hydraulic fluid produced by said self-contained hydraulic supply system;

a self-contained source of electrical power positioned within said at least one housing, wherein said self-contained source of electrical power is the primary source of electrical power for said modular actuator; and

means for releasably coupling said modular actuator to said subsea device.

12. The modular actuator of claim 11, wherein said self-contained hydraulic supply system is adapted to supply a pressurized fluid employed in actuating a subsea valve.