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(54) VALVE SEQUENCE INTERLOCK SYSTEM

(71) We, FMC CORPORATION, a corporation organised and existing under the laws of the State of Delaware, United States of America, of 111 E. Wacker Drive, Chicago, State of Illinois, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

According to the present invention, there is provided a fluid flow control system for a well conduit, comprising a plurality of fluid-actuable valves installed in series relationship in a well conduit, a pressure-fluid conduit system connected to each of said valves and pressure-fluid source means for actuation of said valves, a plurality of pressure-fluid control valves each positioned in said pressure-fluid conduit system for individual regulation of the admission of pressure fluid from said pressure-fluid source means to said fluid-actuable valves, and an interlock system for ensuring the operation of said fluid-actuable valves in a predetermined sequence, said interlock system including locking means actuable to prevent operation of first and second ones of said plurality of pressure-fluid control valves, and control means for said locking means, said control means interconnecting said locking means and said pressure-fluid conduit system so that said locking means is actuated when a third one of said pressure-fluid control valves is in a predetermined first condition and de-activated when said third pressure-fluid control valve is in a predetermined second condition, whereby placing said third pressure-fluid control valve in said first condition results in opening of a corresponding one of said fluid-actuable valves and activation of said locking means to prevent operation of the second and third pressure-fluid control valves and corresponding fluid-actuable valves, and placing said third pressure-fluid control valve in said second condition results in closing said one of fluid-actuable valve and de-activation of said locking means to enable operation of the second and third pressure-fluid control valves and corresponding fluid-actuable valves.

According to the present invention, there is further provided a valve sequence interlock system for use in an offshore well platform completion to control the operation of a plurality of safety valves installed series in a well flow conduit, said platform completion including first and second control valves individually connected to first and second said safety valves by first and second pressure fluid lines, said interlock system comprising controllable locking means actuable to prevent operation of said second control valve, and thus operation of said second safety valve, when said first safety valve is open, and fluid conduit means interconnecting said locking means and said first pressure line to conduct pressure fluid to said locking means when said first control valve is open.

Still further according to the present invention there is provided a valve sequence interlock system for use to control the operation of a plurality of safety valves connected in series in a conduit and having first and second control valves individually connected to first and second said safety valves by first and second pressure fluid lines, said system comprising locking means actuable to prevent operation of said second control valve and thereby operation of said second safety valve when the first safety valve is open, and fluid conduit means interconnecting said locking means and said first pressure line to conduct pressure fluid to said locking means when the first control valve is open.

One embodiment of a valve sequence interlock system in accordance with the invention will now be described, by way of example, with reference to the

accompanying diagrammatic drawings, in which:

Figure 1 is a perspective view of an offshore oil well platform completion employing downhole, subsea, and surface safety valves in each tubing string;

Figure 2 is a front elevation, partially broken away, of an individual well control panel as used in the completion depicted in Figure 1, showing one embodiment of an interlock system in accordance with the invention employed to lock a pair of hydraulically-actuable control valves in their open position;

Figure 3 is a side elevation of the panel of Figure 2, with parts broken away better to illustrate the elements of one of the control valves and the pneumatically-actuable cylinder for locking it; and

Figure 4 is a diagram of the valve interlock system, showing a pneumatically-operable control valve in its closed position, i.e., venting pneumatic pressure from the closed, surface, safety valve with which it is associated, and also showing the pneumatically-actuable cylinders disengaged from the hydraulically-actuable control valves, one control valve being closed, and the other control valve being open.

Referring first to Fig. 1, the embodiment is primarily intended for employment with an offshore oil or gas well platform completion 10, comprising a well platform 12 supported on pilings 14 extending from the ocean floor or mudline 16 to a suitable level above the water's surface, and one or more offshore wells positioned either below the platform at 18 or laterally thereform as at 20.

To ensure maximum safety and control, the wells 18, 20 are each completed with three "fail-close" safety valves 22, 24 and 26 in series in each of the tubing strings 28. In each of these three-valve arrangements the valve 22 is located downhole in the string below the mudline 16, the valve 24 is positioned in the string in a subsea location either at the mudline, such as in a subsea tree 30 or 32, or at some suitable location between the mudline and the water's surface, such as in a subsea tree 34 positioned approximately sixty-six feet below the surface, and the valve 26 is located on the platform where it is readily accessible for quick and easy servicing or replacement. Thus, with flow proceeding in the normal direction from the well to the platform the valves 26 are in the most downstream position, the valves 22 are in the most upstream position, and the valves 24 are in a position intermediate therebetween.

Each of the safety valves 22, 24, is of the "fail-close", hydraulically-actuatable type commonly employed in offshore completions, and the surface safety valve is also a "fail-close" type but is pneumatically-actuatable.

Actuation of the surface safety valves 26 can be achieved with, for example, a 30 p.s.i. pneumatic-supply, the subsea safety valves 24 with a 1500 p.s.i. hydraulic supply, and the downhole safety valves with a 6000 p.s.i. hydraulic supply, each supply source being connected to the related valves by fluid lines in the usual manner. Accordingly, when the pressure from a supply source is admitted to the actuator of a valve the valve will open, and when the pressure is removed, either by rupture or other failure of the fluid line or by venting the line either to atmosphere (in the case of a pneumatic system) or to a reservoir (as in a hydraulic system), the valve will automatically close.

In order that the erosive forces of fluid flow through the valves 22, 24, 26 be restricted as much as possible to the surface valves 26, so that servicing and/or replacement can be accomplished in the most efficient manner, it is necessary to ensure that neither the subsea valves 24 nor the downhole valves 22 are either opened or closed unless the surface valves are closed, thereby preventing fluid flow through the respective flowlines. However, it also is mandatory that each of the safety valves 22, 24, 26 is free to close automatically in the event of an emergency. These requirements are fully satisfied by the embodiment of the interlock system which is illustrated in some detail in Figs. 2—4.

With regard first to Figs. 2 and 3, in the foregoing deseribed offshore platform completion each well 18, 20 is provided with its distinct control planel 40 mounted at a suitable location on the platform 12. Each panel 40 contains an hydraulic control valve 42 in a line 48a, 48b (Figs. 3 and 4) running from an hydraulic pressure supply (not shown) to the well's downhole safety valve 22, an hydraulic control valve 44 in a line 50a, 50b (Fig. 4) between the subsea safety valve 24 and its hydraulic pressure supply (not shown), and a pneumatic control valve 46 in a line 52a, 52b (Fig. 4) from a pneumatic pressure supply to the well's surface safety valve 26. The panel 40 also contains fluid pressure gauges 54, 56, 58 to indicate the pressure in the lines running from the control valves 42, 44, 46 respectively to the downhole, subsea, and surface safety valves 22, 24, 26 respectively.

Each of the three control valves 42, 44, 46 has two functional conditions, designated as "open" and "c" (for "closed") on the panel 40, and changing from one to the other is achieved by rotation of the valves' handles 42a, 44a, 46a approximately ninety degrees

from one designation towards the other. When the pneumatic control valve 46 is opened (Fig. 2) it provides continuity between the line 52a (Fig. 4) from the pneumatic pressure supply (not shown) and the line 52b to the related surface safety valve 26, thereby conducting pressure to this valve 26 which then opens. On the other hand, when the pneumatic control valve 46 is closed as shown in Fig. 4, the line 52a from the pressure supply is shut off and the line 52b from the surface safety valve 26 is vented to the atmosphere, as through a line 47, so that the valve 26 accordingly closes. In similar manner, when the hydraulic control valve 44 is opened (Fig. 2) it conducts fluid pressure from the supply thereof to the line 50b (Fig. 4) running to the subsea safety valve 24, causing the valve 24 to open, and when the control valve 44 is closed (Fig. 4) it shuts off the hydraulic supply line 50a and vents the line 50b from the subsea safety valve 24 to a reservoir (not shown) for the hydraulic fluid, with the result that the valve 24 closes. The hydraulic control valve 42 functions in analogous fashion to the control valve 44, i.e., when it is opened (Fig. 3 and 4) it conducts hydraulic pressure in the line 48a from the supply thereof to the line 48b running to the related downhole valve 22, causing this valve 22 to open, and when the valve 42 is closed (not shown) it shuts off the line 48a and vents the line 48b to a fluid reservoir, thereby causing the valve 22 to close.

In order to ensure that neither of the hydraulic control valves 42, 44 is operated while the pneumatic control valve is open, thereby ensuring that neither the downhole safety valve 22 nor the subsea safety valve 24 is opened or closed while the surface safety valve is open, a pair of pneumatic cylinders 60, 62 (Figs. 2 and 3) is mounted on the panel 40 and oriented so that their piston rods 60a, 62a which are axially slidable in threaded positioning elements 60b, 62b, and guides 60c, 62c, respectively, extend toward cylindrical stems 42b, 44b, respectively, of the hydraulic control valve handles 42a, 44a, repectively. The outer periphery of the valve handle stem 42b is provided with dimples or holes 64, 66 spaced approximately 90° apart, and in similar manner the valve handle stem 44b is dimpled at 68, 70. The spacial relationship between the cylinder 60 and the dimples 64, 66 is such that when the control valve 42 is open the cylinder's piston rod 60a is aligned with the dimple 66, and when the valve 42 is closed the piston rod 60a and the dimple 64 are in alignment. Likewise, the spacial relationship between the cylinder 62 and the dimples 68, 70 results in the piston rod 62a and the dimple 70 being in alignment when the control valve 44 is open, and when this valve is closed the dimple 68 lines up with the piston rod 62a.

The illustrated cylinders 60, 62 are of the single-acting, spring return variety, and are connected by pneumatic branch lines 72, 74 respectively, and a trunk 76 to the pneumatic line 52b running from the pneumatic control valve 46 to the surface safety valve 26. Accordingly, when the control valve 46 is open (Figs. 2 and 3) the pneumatic pressure coming from the supply through line 52a is conducted to the cylinders 60, 62 as well as to the surface safety valve 26. This pressure extends the cylinders' piston rods 60a, 62a into the respective control valve handle dimples that happen to be in alignment therewith, securely locking the handles against rotation and this preventing their valves and the safety valves 22, 24 from being operated. When the control valve 46 is closed (Fig. 4) the return spring 78 in the cylinder 62 and the return spring (not shown) in the cylinder 60 retract the piston rods 62a, 60a, respectively, thereby disengaging these rods from the dimples and freeing the control valve handles 42a, 44a for rotation to either open or close the downhole and subsea safety valves 22, 24 respectively.

From the foregoing it can be seen that the interlock system of the hereinbefore described embodiment provides a positive, efficient, and highly satisfactory means for ensuring that the downhole and subsea safety valves of a three-valve safety completion system in an offshore oil or gas well can not be operated by an attendant or other personnel unless the surface safety valve is closed, and that this interlock system interferes in no way with the required automatic closure of any and all of these three safety valves when an emergency occurs or pressure to them is otherwise removed.

WHAT WE CLAIM IS:—

1. A fluid flow control system for a well conduit, comprising a plurality of fluid-actuable valves installed in series relationship in a well conduit, a pressure-fluid conduit system connected to each of said valves and pressure-fluid source means for actuation of said valves, a plurality of pressure-fluid control valves each position in said pressure-fluid conduit system for individual regulation of the admission of pressure fluid from said pressure-fluid source means to said fluid-actuable valves, and an interlock system for ensuring the operation of said fluid-actuable valves in a predetermined sequence, said interlock system including locking means actuable to prevent operation of first and second ones

from one designation towards the other. When the pneumatic control valve 46 is opened (Fig. 2) it provides continuity between the line 52a (Fig. 4) from the pneumatic pressure supply (not shown) and the line 52b to the related surface safety valve 26, thereby conducting pressure to this valve 26 which then opens. On the other hand, when the pneumatic control valve 46 is closed as shown in Fig. 4, the line 52a from the pressure supply is shut off and the line 52b from the surface safety valve 26 is vented to the atmosphere, as through a line 47, so that the valve 26 accordingly closes. In similar manner, when the hydraulic control valve 44 is opened (Fig. 2) it conducts fluid pressure from the supply thereof to the line 50b (Fig. 4) running to the subsea safety valve 24, causing the valve 24 to open, and when the control valve 44 is closed (Fig. 4) it shuts off the hydraulic supply line 50a and vents the line 50b from the subsea safety valve 24 to a reservoir (not shown) for the hydraulic fluid, with the result that the valve 24 closes. The hydraulic control valve 42 functions in analogous fashion to the control valve 44, i.e., when it is opened (Fig. 3 and 4) it conducts hydraulic pressure in the line 48a from the supply thereof to the line 48b running to the related downhole valve 22, causing this valve 22 to open, and when the valve 42 is closed (not shown) it shuts off the line 48a and vents the line 48b to a fluid reservoir, thereby causing the valve 22 to close.

In order to ensure that neither of the hydraulic control valves 42, 44 is operated while the pneumatic control valve is open, thereby ensuring that neither the downhole safety valve 22 nor the subsea safety valve 24 is opened or closed while the surface safety valve is open, a pair of pneumatic cylinders 60, 62 (Figs. 2 and 3) is mounted on the panel 40 and oriented so that their piston rods 60a, 62a which are axially slidable in threaded positioning elements 60b, 62b, and guides 60c, 62c, respectively, extend toward cylindrical stems 42b, 44b, respectively, of the hydraulic control valve handles 42a, 44a, repectively. The outer periphery of the valve handle stem 42b is provided with dimples or holes 64, 66 spaced approximately 90° apart, and in similar manner the valve handle stem 44b is dimpled at 68, 70. The spacial relationship between the cylinder 60 and the dimples 64, 66 is such that when the control valve 42 is open the cylinder's piston rod 60a is aligned with the dimple 66, and when the valve 42 is closed the piston rod 60a and the dimple 64 are in alignment. Likewise, the spacial relationship between the cylinder 62 and the dimples 68, 70 results in the piston rod 62a and the dimple 70 being in alignment when the control valve 44 is open, and when this valve is closed the dimple 68 lines up with the piston rod 62a.

The illustrated cylinders 60, 62 are of the single-acting, spring return variety, and are connected by pneumatic branch lines 72, 74 respectively, and a trunk 76 to the pneumatic line 52b running from the pneumatic control valve 46 to the surface safety valve 26. Accordingly, when the control valve 46 is open (Figs. 2 and 3) the pneumatic pressure coming from the supply through line 52a is conducted to the cylinders 60, 62 as well as to the surface safety valve 26. This pressure extends the cylinders' piston rods 60a, 62a into the respective control valve handle dimples that happen to be in alignment therewith, securely locking the handles against rotation and this preventing their valves and the safety valves 22, 24 from being operated. When the control valve 46 is closed (Fig. 4) the return spring 78 in the cylinder 62 and the return spring (not shown) in the cylinder 60 retract the piston rods 62a, 60a, respectively, thereby disengaging these rods from the dimples and freeing the control valve handles 42a, 44a for rotation to either open or close the downhole and subsea safety valves 22, 24 respectively.

From the foregoing it can be seen that the interlock system of the hereinbefore described embodiment provides a positive, efficient, and highly satisfactory means for ensuring that the downhole and subsea safety valves of a three-valve safety completion system in an offshore oil or gas well can not be operated by an attendant or other personnel unless the surface safety valve is closed, and that this interlock system interferes in no way with the required automatic closure of any and all of these three safety valves when an emergency occurs or pressure to them is otherwise removed.

WHAT WE CLAIM IS:—

1. A fluid flow control system for a well conduit, comprising a plurality of fluid-actuable valves installed in series relationship in a well conduit, a pressure-fluid conduit system connected to each of said valves and pressure-fluid source means for actuation of said valves, a plurality of pressure-fluid control valves each position in said pressure-fluid conduit system for individual regulation of the admission of pressure fluid from said pressure-fluid source means to said fluid-actuable valves, and an interlock system for ensuring the operation of said fluid-actuable valves in a predetermined sequence, said interlock system including locking means actuable to prevent operation of first and second ones

of said plurality of pressure-fluid control valves, and control means for said locking means, said control means interconnecting said locking means and said pressure-fluid conduit system so that said locking means is actuated when a third one of said pressure-fluid control valves is in a predetermined first condition and de-activated when said third pressure-fluid control valve is in a predetermined second condition, whereby placing said third pressure-fluid control valve in said first condition results in opening of a corresponding one of said fluid-actuable valves and activation of said locking means to prevent operation of the second and third pressure-fluid control valves and corresponding fluid-actuable valves, and placing said third pressure-fluid control valve in said second condition results in closing said one fluid-actuable valve and de-activation of said locking means to enable operation of the second and third pressure-fluid control valves and corresponding fluid-actuable valves.

2. A control system according to claim 1 wherein said fluid-actuable valves are fail-closed safety valves.

3. A control system according to claim 2 wherein said safety valves include a downhole valve, a subsea valve and a surface valve.

4. A control system according to any one of claims 1 to 3 wherein said locking means includes two fluid-operable cylinders each with a piston rod and each arranged to co-operate mechanically with a corresponding one of said second and third pressure-fluid control valves.

5. A control system according to claim 4 wherein said control means comprises a pressure-fluid line interconnecting said fluid-operable cylinders and that portion of said fluid conduit system interconnecting said first pressure-fluid control valve and the corresponding said fluid-actuable valve.

6. A control system according to claim 5 wherein each said fluid-operable cylinder is a single-acting, spring-return cylinder, said first and second pressure-fluid control valves each has a rotatable handle that is engaged and held against rotation by the corresponding said piston rod when said cylinder is subjected to pressure fluid, and said one fluid-actuable valve is the surface safety valve.

7. A control system according to claim 6 including a said pressure-fluid control valve associated with each of said subsea and downhole valves, and a said fluid-operable cylinder of each control valve to prevent operation of said subsea and down hole fluid-actuable valves and their control valves when said surface safety valve is open.

8. A valve sequence interlock system for use in an offshore well platform completion to control the operation of a plurality of safety valves installed in series in a well flow conduit, said platform completion including first and second control valves individually connected to first and second said safety valves by first and second pressure fluid lines, said interlock system comprising controllable locking means actuable to prevent operation of said second control valve, and thus operation of said second safety valve, when said first safety valve is open, and fluid conduit means interconnecting said locking means and said first pressure line to conduct pressure fluid to said locking means when said first control valve is open.

9. A system according to claim 8 wherein the locking means comprises a fluid-operable cylinder with a piston rod actuable by admission of pressure fluid.

10. A system according to claim 9 wherein said second control valve includes a rotatable handle with means engageable by said piston rod to prevent rotation of said handle, and thus operation of said control valve.

11. A system according to claim 10 wherein said fluid-operable cylinder is a single-acting, spring-return unit arranged so that its piston rod extends into locking engagement with said second control valve handle upon opening said first control valve, and said piston rod retracts from said locking engagement is response to spring-return action when said first control valve is closed.

12. A system according to claim 11 including a third control valve, a fluid operable cylinder for preventing operation of said third control valve, and fluid conduit means interconnecting said third control valve fluid-operable cylinder to said first pressure line.

13. A system according to claim 12 wherein said third control valve controls the admission of pressure fluid to a third safety valve.

14. A system according to claim 13 wherein said system acts to prevent the operation of said second and third safety valves by operation of said second and third control valves unless said first safety valve is closed.

15. A valve sequence interlock system for use to control the operation of a plurality of safety valves connected in series in a conduit and having first and second control valves individually connected to first and second said safety valves by first and second pressure fluid lines, said system comprising locking means actuable to prevent operation of said second control valve and

thereby operation of said second safety valve when the first safety valve is open, and fluid conduit means interconnecting said locking means and said first pressure line to conduct pressure fluid to said locking means when the first control valve is open.

16. A valve sequence interlock system substantially as hereinbefore described with reference to the accompanying drawings.

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