TESTING A SOLENOID OF A DIRECTIONAL CONTROL VALVE

Field of the Invention

The present invention relates to testing a solenoid of a directional control valve in a subsea hydrocarbon production control system.

Background of the Invention

Continuously energised electro-hydraulic, solenoid operated directional control valves (DCVs) are often used in subsea well electro-hydraulic production control systems in safety related or safety critical applications where loss of electrical power, or the detection of a dangerous condition, results in the de-energising of a coil of the DCV solenoid and the resultant closure, and hydraulic pressure venting, of the hydraulic supply. Under these conditions, it is therefore critical that an armature of the DCV solenoid not stick in the open position after the solenoid coil is de-energised. However, since such continuously energised valves are often energised for extended periods of time, it cannot be guaranteed that the armature of a DCV solenoid will move to close the valve when demanded to do so by de-energising the solenoid coil.

A known form of monitoring or testing a solenoid of a DCV in a subsea hydrocarbon production control system is described in EP-A-2 053 289. Other forms of monitoring or testing solenoids are described in: US-A-6 917 203; GB-A-2 110 373; US-A-5 153 522; US-A-5 796 201; US-A-6 211 665; US-A-6 326 898; US 2006/0285265; US-A-5 245 501; DE-A-3 624 231; and US-A-5 241 218.

Summary of the Invention

According to the present invention from one aspect, there is provided a method of testing a solenoid of a directional control valve in a subsea hydrocarbon production system, the solenoid having a coil and an armature for operating the valve and the coil being energised by a drive voltage across it, the method comprising removing or reducing the drive voltage and sensing current through the coil to produce an indication of movement of the armature.

According to the present invention from another aspect, there is provided a subsea hydrocarbon production control system, comprising a directional control valve having a solenoid which has a coil and an armature for operating the valve, the system including means for applying a drive voltage across the coil for moving the armature and testing

means which comprise means for removing or reducing the drive voltage and means for sensing current through the coil to produce an indication of movement of the armature.

Said drive voltage could be reduced by pulse width modulation of voltage applied by drive circuitry for the solenoid.

Preferably, said indication is produced by detecting a perturbation of said current due to a change in the inductance of said coil due to movement of the armature.

In one embodiment, if said drive voltage is removed or reduced but no such indication is produced before it reaches zero, the voltage is increased to said drive voltage and then reduced again.

Typically, said drive voltage is removed or reduced by processor means in a subsea electronics module of a subsea control module.

Typically, said voltage is returned to said drive voltage in response to said indication.

An embodiment of this invention is the testing of a DCV solenoid at regular intervals, during extended periods of continuous activation of the DCV solenoid drive circuit, by performing partial closure (but not full closure) of the DCV by removing or gradually reducing the DCV solenoid drive current for a short interval, sufficiently long enough for the DCV solenoid armature to start to move toward the closed position. During this DCV solenoid coil current removal or reduction interval, the solenoid current is monitored, to detect the perturbation (a distinct 'kick' in the current flow) resulting from the change of inductance of the solenoid coil due to movement of the armature of the solenoid. Lack of detection of the perturbation indicates that the DCV solenoid armature has stuck, whereby an alarm is sent to the well operator.

Brief Description of the Drawings

Fig. 1 is a block diagram showing items for energizing the coil of a DCV solenoid in an embodiment of the invention;

Fig. 2 shows voltage and current waveforms occurring in operation of the embodiment; and

Fig. 3 is a schematic view of a subsea hydrocarbon production control system incorporating the invention.

Description of an Embodiment of the Invention

Fig. 1 illustrates an arrangement for the operation and control of a DCV in the production control system of a subsea hydrocarbon well. The well control system may include a number of processors, typically housed in a subsea electronics module (SEM), at least one of which will control all of the DCVs on the well, which are housed, along with the SEM, in a subsea control module (SCM) mounted on a well tree. Typically, a DCV is operated by energising the coil of its solenoid 1 from a DC power supply switched on by a power driver 2 from a control signal (on/off) from a processor 3. For this invention, current sensing circuitry in the form of a current sensor 4 detects the current in the coil of the DCV solenoid and modified software in the processor 3 controls the power driver 2 by pulse width modulation (PWM) to provide a variable output to the solenoid coil. The power driver 2 is typically a simple transistor, but instead of simply turning it off and on to operate the solenoid, the processor produces a control on a line 5 to provide the variable voltage required for the embodiment of this invention.

Fig. 2 shows how the current in the coil of DCV solenoid (lower graph) is varied by changing the applied voltage (upper graph) by PWM under the control of the modified software in the processor 3. The mode of operation, controlled by the software in the processor 3, is as follows.

The energised coil of DCV solenoid 1 has a full operating voltage 6 applied, resulting in an operating current 7 determined by the resistance of the solenoid coil. To test the solenoid to check that its armature is not stuck, the processor 3 produces a varying voltage 8 by PWM to the power driver 2, resulting in a reduction of the mean voltage applied to the coil of the DCV solenoid 1 and thus a reduction in the mean current 9. When the current has fallen to the point where the solenoid armature begins to move towards its return state, the resultant perturbation 10 in the current (due to a change in the inductance of the solenoid coil) is sensed by the current sensor 4 and an indication of this is sent to the processor 3, which is programmed to immediately return the supply voltage to the full supply 11. The current in the solenoid coil then rises as shown by reference 12, exponentially, due to the inductance of the coil of the solenoid, to its normal operating state 13 to prevent any further movement of the solenoid armature and to return it to its fully operated state. The process is implemented rapidly so that the movement of the armature DCV solenoid is small and the DCV is not closed and thus there is substantially no effect on the well operation. The processor 3 performs the above operation as often as the well operator requires. For example, if the current in the solenoid falls to zero without a current perturbation, the power

supply is immediately reverted to full and the process repeated a number of times. A continual lack of current perturbation will finally result in the processor sending an alarm to the well operator via the well to surface communication system.

Instead of gradually reducing the voltage across the solenoid coil, the processor 3 could cause removal of it for a short time interval, say 10 milliseconds, insufficient to close the DCV, whereby the current collapses very quickly to a point where the armature starts to move again. Because the armature moves, the inductance of the solenoid will change and because the inductance changes the current briefly goes up again to produce a perturbation like perturbation 10 which is detected by sensor 4.

Referring to Fig. 3, this shows schematically a subsea hydrocarbon production control system incorporating the invention. In a subsea control module (SCM) 14 there is a subsea electronics module (SEM) 15 and a hydraulic control module (HCM) 16. The SCM 14 is fed by an umbilical 17 from a topside master control station (MCS) 18, e.g. at a surface platform, with electric power, control signals and hydraulic power. The control signals are processed by the SEM 15 which then controls solenoid operated, hydraulic directional control valves (DCVs) D1-Dn in the HCM 16 which in turn operate a multiplicity of hydraulic devices such as actuators for controlling a subsea hydrocarbon production well. The subsea control system is located at a well tree, the SCM 14 being connected to the umbilical 17 via a distribution unit 19 which provides the electric power and control signals to the SEM 15 via a cable 20 and hydraulic power to the HCM 16 via a feed 21. The SEM 15 controls the DCVs D1 – Dn in the HCM 16 via a cable 22.

In accordance with the invention, the SEM 15 includes a processor 3 for use in testing a DCV whose coil is continuously energised, in a manner as described above, any such alarm as described above being sent from processor 3 to the MCS 18. For clarity, current sensor(s) 4 and driver(s) 2 have been omitted from Fig. 3.

Although the application described above is 'closed loop' it is possible to implement the invention by 'open loop' control when desired via the well operator from a control station.

Advantages of using the Invention

This invention offers enhanced protection against the occurrence of a failure when a continuously energised DCV is demanded to close and reduces the likelihood of undisclosed failures.

CLAIMS:

1. A method of testing a solenoid of a directional control valve in a subsea hydrocarbon production system, the solenoid having a coil and an armature for operating the valve and the coil being energised by a drive voltage across it, the method comprising removing or reducing the drive voltage and sensing current through the coil to produce an indication of movement of the armature.

2. A method according to claim 1, wherein said drive voltage is reduced by pulse width modulation of voltage applied by drive circuitry for the solenoid.

3. A method according to claim 1 or 2, wherein said indication is produced by detecting a perturbation of said current due to a change in the inductance of said coil due to movement of the armature.

4. A method according to any preceding claim, wherein if said drive voltage is removed or reduced but no such indication is produced before it reaches zero, the voltage is increased to said drive voltage and then reduced again.

5. A method according to any preceding claim, wherein said drive voltage is removed or reduced by processor means in a subsea electronics module of a subsea control module.

6. A method according to any preceding claim, wherein said voltage is returned to said drive voltage in response to said indication.

7. A subsea hydrocarbon production control system, comprising a directional control valve having a solenoid which has a coil and an armature for operating the valve, the system including means for applying a drive voltage across the coil for moving the armature and testing means which comprise means for removing or reducing the drive voltage and means for sensing current through the coil to produce an indication of movement of the armature.

8. A system according to claim 6, wherein said means for reducing the drive voltage comprises means for pulse width modulation of voltage applied by drive circuitry for the solenoid.

9. A system according to claim 7 or 8, wherein said sensing means includes means for producing said indication by detecting a perturbation of said current due to a change in the inductance of said coil due to movement of the armature.

10. A system according to any of claims 7 to 9, wherein said testing means is adapted to increase said voltage to said drive voltage and then remove or reduce it again if no such indication is produced before said voltage reaches zero.

11. A system according to any of claims 7 to 10, wherein said voltage removing or reducing means includes processor means in a subsea electronics module of a subsea control module.

12. A system according to any of claims 7 to 11, wherein said testing means is adapted to return said voltage to said drive voltage in response to said indication.