Development of 3000 m Subsea Blowout Preventer Experimental Prototype

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Abstract. A subsea blowout preventer experimental prototype is developed to meet the requirement of training operators, and the prototype consists of hydraulic control system, electronic control system and small-sized blowout preventer stack. Both the hydraulic control system and the electronic system are dual-mode redundant systems. Each system works independently and is switchable when there are any malfunctions. And it significantly improves the operation reliability of the equipment.

1. Introduction

Complex mechatronic system such as subsea blowout preventer (BOP) system requires high reliability [1–5]. Cai et al. proposed a GMR-based data acquisition and supervisory control system [6], Cai et al. also proposed BN-based real-time reliability evaluation system for 3000 m BOP [7]. To avoid accidents, reliable design, manufacture, operation and maintenance are required. Therefore, it is necessary to train operators effectively to ensure the operational reliability of operators. An extremely reliable BOP control system and an experimental prototype are developed in this paper.

2. Development of Hydraulic control system

Hydraulic control system of the subsea BOP experimental prototype is a dual-mode redundant control system, which consists of blue control case and yellow control case. The hydraulic circuit is shown in Fig. 1. Take BOP NO.1 as an example to explain the control principle. When the pilot valve is powered on and begin to reverse, the low-pressure oil flows into the control inlet of the electro-hydraulic valve, which drives the hydraulic valve to reverse. Then the high-pressure oil flows into the closing chamber of the BOP through shuttle valve, and the BOP completes the closing movement with oil pressure. To seal the oil well for a long time without providing persistent high oil pressure, a retaining mechanism is designed to lock the state of BOP after closing movement, and the retaining mechanism requires relative much lower oil pressure. The unlocking and opening movements of the BOP are completely opposite. The components and working principle of the yellow case are completely the same with the blue case, the yellow case works as a substitution when a failure occurs in blue case. And the shuttle valve between them makes the two redundant systems independent from
each other without mutual interference. The working principles of BOP NO.2 and NO.3 are similar with BOP NO.1. Considering the working pressures of ram type preventer and annular preventer are different, pressure reducing valves are designed before the BOPs to achieve secondary adjustment of oil pressure.

![Hydraulic control system of subsea BOP experimental prototype](image)

**Figure 1.** Hydraulic control system of subsea BOP experimental prototype

### 3. Development of Electronic control system

Electronic control system of the subsea BOP experimental prototype consists of NI control system and relay control system. Hardware configuration of NI control system is shown in Fig. 2. This system mainly consists of central control unit, Ethernet switch and NI suite. The suite contains two cDAQ9188 cases, two NI9477 data acquisition cards and two NI9405 data acquisition cards. The two sets of equipment are installed in the blue case and the yellow case respectively to simulate the output module and input module in practical production. NI9477 data acquisition card is a digital output equipment, which is used to control the movement of the valves. NI9405 is an analog input equipment, which is used for pressure acquisition. Two cDAQ9188 cases communicate through Ethernet switch and transmit data to the computer.

A control program supporting the hardware configuration is developed based on Labview software. Take control logic of BOP NO.1 as an example. At first, assume the blue case is the default case, and
the program begins to judge if the pressure value collected by pressure sensor PS2B is correct. If yes, the pilot valve of SPM2B will reverse, then the program begins to judge if the pressure value collected by pressure sensor PS9B is correct. If yes, maintain the pressure for 20 seconds and the BOP will finish closing movement. After that, DDV4B will reverse, then the program begins to judge if the pressure value collected by pressure sensor PS5B is correct. If yes, maintain the pressure for 20 seconds and the locking movement will complete. In the meantime, pilot valve of SPM2B will return to original position. If there are any outliers in acquisition of PS2B, PS9B or PS5B, the program will be interrupted and switch to yellow case to continue the same logic. The control flow is similar if the yellow case is chosen as the default case.

Figure 2. Hardware configuration of NI control system

The relay control logic is shown in Fig. 3. Once the motor is started, working states of the pump can be selected by switching the three-selection knob. All BOPs opening or closing movements are controlled by the combination of buttons and contacts of relays, and interlocking is designed between the opening-movement contacts and the closing-movement contacts to avoid conflict. The time-delay relays are designed to accomplish locking movement automatically after the BOP is closed, and accomplish unlocking movement automatically when the BOP needs to be opened. If there is any malfunction happens to the equipment, the alternative button can be switched to change the control case.
4. Development of key components

The mechanical system of subsea BOP experimental prototype mainly consists of ram BOPs, annular BOP and valve blocks. Cai et al. proposed researching and developing methods of ram BOPs [8]. The design of annular BOP and valve blocks is discussed below.

The primary components of annular BOP consist of shell, rubber core, piston, supporting tube and fixture block. The structure is shown in Fig. 4. The rubber core is the core of the BOP, which is a subulate rubber with supporting rods inside. When the piston goes upward, the supporting rods are pressed to the center and pull the rubber to hold the drill pipe. Piston is the key component that transforms the hydraulic energy into mechanical energy, and it is powered by high-pressure oil to push the rubber core to working position.

All valve groups are installed on valve blocks, which reduces connecting lines and improve reliability significantly. Take the valve block shown in Fig. 5 (a) as an example. The whole valve group is shown in Fig. 5 (b), including electro-hydraulic valves SPM1B-SPM4B and reducing valve. The high-pressure oil flows into the reducing valve through P inlet. After pressure setting, the high-pressure oil flows into the block, and the low-pressure oil flows into the block through X inlet directly. Then if any solenoid valve that controls the low-pressure oil reverses from original position, the low-pressure oil will flows into relevant pilot valve and open relevant high-pressure oil inlet, then the high-

![Figure 3. Schematic diagram of relay control logic](image)

![Figure 4. The exploded views of annular blowout preventer](image)
pressure oil flows into relevant oil cylinder and execute opening or closing movement. Pressure sensors are installed near every oil inlet and outlet to measure the pressure. And oil drainage inside the block flows back to the tank through Y and T outlets.

![Diagram of electro-hydraulic valve block and valve group](image)

**Figure 5.** (a) Schematic diagram of electro-hydraulic valve block and (b) the valve group

5. **Test of the entire subsea BOP experimental prototype**

As shown in Fig. 6, the entire experimental prototype contains two control modes, manual operation mode and automatic operation mode. In manual operation mode, users control the prototype by operating buttons and knobs. The oil pressures of key points are displayed by a set of matched industrial monitor meters. Users can activate automatic operation mode by switching the alternative knob. In automatic mode, users control the prototype through operating the upper computer. The interfaces consist of hydraulic control unit (HCU), main control unit (MCU) and fault detecting unit (FDU). The HCU controls the working states of the pump station, the MCU controls movements of BOPs and displays relevant pressure, and the FDU reveals failure unit and the position of failure.

The tests indicate that the two control modes accomplish the function of the subsea BOP experimental prototype perfectly. The prototype is able to simulate the basic function of 3000 m subsea BOP and its control system, and the prototype meets the requirement of training operators completely.
Figure 6. The entire experimental prototype of the subsea BOP system

6. Conclusion
A subsea BOP experimental prototype is developed, and the prototype is able to simulate basic function of a real subsea BOP stack. Both the hydraulic control system and the electronic system are dual-mode redundant systems. Each system works independently and is switchable when there are any malfunctions, which significantly improves the operation reliability of the equipment. The prototype contains two control modes, one is manual mode and the other is automatic mode, correspond to relay control and NI control respectively. The operators can understand working principle and structural composition of subsea BOP stack quickly by training with the prototype. Moreover, both the cost of training and the risk of operating will be greatly reduced. The prototype makes positive contribution to improve working level and occupational qualities of operators.

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