Data Analysis and Discussion on the Reliability of the Control Principle of a Sealed Crude Oil Pipeline

Junjiang Liu, Liang Feng*, Dake Yang and Xianghui Li
PipeChina Southwest Company, 610094 Chengdu, China

*Corresponding author email: fenglangtc@126.com

Abstract. The current control principles of long-distance crude oil pipeline production and operation are all obtained by theory in the design stage, and lack of on-site actual operation verification. Based on the pigging data of the pipeline put into production in 2017, the simulation software SPS was used to establish the model. Based on the operating data of the pipeline in recent years, the control principles in the preliminary design are checked one by one to verify the reliability of the control principles and propose corresponding improvement suggestions for existing defects. The research results show that the initial control principle of the pipeline has two actual operation defects. One is the low setting value of the water hammer pressure relief valve in the BS station, and the second is the advance protection program error under the failure condition of the MD station; The simulation obtains the set value of the pressure relief limit of each station entry and exit under the principle of advanced protection, and the set value can be adjusted appropriately according to the pressure of the entry and exit pipelines of each station; the response time of each step of the control principle under different fault conditions is simulated, Provide optimization suggestions for some control principles. The above research results can minimize the failure results produced by the failure conditions under the premise of ensuring the effective control principle.

Keywords: Pressure relief limit; Crude oil pipeline; Control principle; Reliability; Closed transportation.

1. Introduction
Currently, most crude oil transportation uses long-distance pipelines for closed transportation. The research and development of crude oil pipeline transportation technology such as and magnetic treatment fully demonstrate the advantages of long-distance pipeline closed transportation. Later, scholars conducted research on its safety, reliability and automation. Dong et al. (2015)A brief analysis of the fully enclosed transportation process and discussion of its safety measures are provided to provide reference for the research on improving the safety of crude oil transportation; Yu (2018) uses computers as the core in the automatic control of the Lun-Ku-Shan crude oil pipeline Data acquisition and monitoring system (SCADA), which can monitor, dispatch and manage the entire line at the Urumqi Dispatching Control Center. Remote monitoring has improved the automation management level of pipeline operation; scholars have also studied the problems existing in the closed transportation of long-distance pipelines. Liu and Teng (2019) discussed common problems and solutions in the closed transportation of crude oil pipelines Analysis and discussion were carried out. There are few researches on control principle of airtight crude oil pipeline at home and abroad. This paper is based on a closed long-distance crude oil pipeline, using simulation software to model it, and verifying and revising the control principle one by one with its actual operating data in recent years. The research direction is the reliability of the control principle and the reliability of the advanced...
protection of the closed crude oil pipeline. The principle of advance protection is that when water shock is generated, the pipeline control center will give instructions to the upstream and downstream pumping stations quickly, and the upstream and downstream pumping stations will take corresponding protection actions immediately to generate a disturbance opposite to the water shock pressure wave. After the two waves meet, part of the water shock pressure wave will be offset to avoid harm to the pipeline.

2. Materials and Methods
There are 4 pumping stations (RL, MS, BS, MD), 1 sub-station (LF) and 1 terminal station (AL) in a long-sealed crude oil transmission pipeline with a design capacity of 1300×10⁴t/a. Since the first station has 150,000 cubic meters of storage tanks, the closed pipeline is a separate water conservancy system. The crude oil pipeline can be modeled with SPS simulation software for qualitative research. The crude oil pipeline was put into operation in 2017, and about three years of operation data have been accumulated, which can be used to verify the reliability of its control principle. Combining the operating data of the pipeline in recent years, the control principles in the preliminary design are checked one by one to verify the reliability of the control principles and propose corresponding improvement suggestions for existing defects. The oil selected in this paper is STQ oil, and the reliability of the control principle and advance protection setting is studied under the design volume. Table 1 shows the steady-state operating parameters of the crude oil pipeline.

Table 1. Research on the steady-state operating parameters of crude oil pipelines (1300×10⁴t/a).

| Station name | Incoming pressure | Outbound pressure | Outbound temperature | Number of pumps opened | Total number of pumps |
|--------------|-------------------|-------------------|----------------------|------------------------|----------------------|
| RL           | 0.02              | 1.12              | 28                   | 3                      | 4                    |
| RL           | 1.12              | 7.79              | 29.2                 | 4                      | 5                    |
| MS           | 5.31              | 12.61             | 28.5                 | 4                      | 5                    |
| BS           | 4.06              | 10.19             | 28.1                 | 1                      | 2                    |
| MD           | 7.39              | 9.09              | 24.2                 |                        |                      |
| LF           | 7.49              | 7.48              |                      |                        |                      |
| AL           | 2.72              |                   |                      |                        |                      |

3. Results and Discussion

3.1. Research on Reliability of Control Principle
Based on Table 1, all the failure-triggered advance protectors in the initialization are simulated sequentially. Simulated faults include pump rejection, ESD valve shutdown in and out of the station, and monitoring valve chamber shutdown. In view of the above three types of failures, one in turn is selected for the reliability analysis of the control principle.

Case 1: MD station dump pump fault conditions
The control principle is as follows: (1) Stop 1 external main pump in BS station; At the same time, the setting value of BS outbound regulating valve was changed to 10.9MPa, and the setting value of AL terminal inlet pressure reducing valve was changed to 4.22MPa; (2) 60s after the execution of step 1, change the setting value of the MS pumping station outbound regulating valve to 12.7MPa; (3) 30s after the execution of step 2, stop one main oil delivery pump of the RL pumping station, and change the setting value of the outbound regulating valve of the RL pump station is changed to 7.45MP; (4) The program is automatically processed. Conclusion: The oil pump of MD pumping station is out of operation. After the above control procedure is adopted within 60s, the pipeline will reduce the transportation volume, and the transportation volume will be 1390m³/h. The simulation results show that the pressure relief tank of the BS station will be full. Through analysis of the reasons, after the entire line of reduced volume transportation, the inbound pressure of the BS station is greater than the trigger value of the water hammer pressure relief valve at this point, causing the pressure relief valve to be normally open. Therefore, the control principle is flawed and needs to be corrected immediately. After many simulations, the reliable control principle under this fault condition is as follows: (1) Stop all feed pumps and oil main pumps at RL pumping station, and stop all external main pumps at MS pumping station, BS pumping station and MD pumping station; (2) 60s after step 1 is executed,
The inbound pressure reducing valve of the last station is set to 0 opening, and the shutoff valves upstream and downstream of the pressure reducing valve are closed; (3) The outlet regulating valves of all pump stations on the whole line are set to 0 opening, and the upstream and downstream shutoffs of the regulating valve are closed. Valve; (4) The program is automatically processed. The above control logic needs to be activated within 30s after the fault to ensure that the entire line will not be over pressured under the fault condition.

**Case 2: The ESD valve of a BS pumping station is shut down accidentally (the valve is fully shut down for 180s)**

The control principle of the fault condition is as follows: the ESD valve in the BS pump station is shut down by accident, and the following instructions must be executed in order within 30s after the valve leaves the fully open position to achieve pipeline shutdown: (1) Shut down all RL pump stations Oil feed pumps and main oil pumps, and stop all main pumps of MS pumping station and BS pumping station at the same time; (2) 30s after step 1 is executed, stop all main oil pumps of MD pumping station; (3) 30s after the execution of step 2, set the inbound pressure reducing valve of the AN end station to 0 opening, and close the shutoff valves upstream and downstream of the pressure reducing valve; (4) Set the outbound regulating valve of all pump stations across the line to 0 opening, And close the shutoff valve upstream and downstream of the regulating valve. The program is automatically processed. Conclusion: The ESD valve in the BS pumping station is shut down by accident. After the above control procedures are adopted within 30s, the pipeline will not be over pressured. The simulation results show that the control logic can ensure that the entire line does not overpressure. However, the oil discharged from BS Station exceeds 60 cubic meters, and further research is needed to address this issue.

**Case 3: E120 line monitoring shut-off valve accidentally shuts down (the full shut-off time of the valve is 180s)**

The control principle of the fault condition is as follows: The E120 line monitoring cutoff valve accidentally shuts down, and the following instructions must be executed in order within 120s after the valve leaves the fully open position to achieve pipeline shutdown: (1) Shut down all the oil pumps in the RL pump station And the main oil pumps, and stop all the main pumps of MS pumping station, BS pumping station and MD pumping station at the same time; (2) 60s after the execution of (1), set the AN last station inbound pressure reducing valve to 0 Opening degree, and close the shutoff valves upstream and downstream of the pressure reducing valve; (3) Set the outbound regulating valves of all pump stations across the line to 0 opening degree, and close the shutoff valves upstream and downstream of the regulating valve; (4) The program is automatically processed. Conclusion: The E120 line monitoring cut-off valve is accidentally shut down. After the above control procedures are adopted within 120s, the entire pipeline will not be over pressured. XThe simulation results show that the control logic can ensure that the entire line does not overpressure. However, the oil discharged from BS Station exceeds 60 cubic meters, and further research is needed to address this issue.

Through the simulation of three fault conditions, it is concluded that it is necessary to further study the water hammer pressure value of BS station; follow the same method to verify the control logic of all fault conditions, and two unreasonable points are found after simulation. Two unreasonable reasons include: First, the BS station's inbound water hammer pressure relief setting value is too low. Under most fault conditions, the water hammer pressure relief valve will trigger action, and the oil discharge volume under some fault conditions More than 60 parties. This will cause a lot of hidden risks and bring a greater amount of extra work to the site. After communicating with the initial design party, the change of the water hammer pressure relief setting value at this point has been completed (the setting value is changed from 4.7MPa to 5.2MPa); the second is the hidden danger in the above example. The reason has been clearly analyzed. The recommendation is to follow the revised control logic is corrected.

From what has been discussed above, this study found that the control principle of the closed crude oil long-distance pipeline has two major hidden dangers, which were modified after coordination with the original establishment; after this modification, the control principle is further strengthened under fault conditions the reliability.
3.2. Reliability of Advanced Protection Settings

Based on Table 1, the limit value of the water hammer relief valve setting value of each station of the crude oil pipeline is studied in turn according to the following method. The methods adopted are as follows: (1) The steady state in Table 1 is taken as the initial state of simulation; (2) Close the water hammer pressure relief valves of all stations in the model; (3) Call a fault condition control with edited control logic. The logic starts to simulate; (4) After completing the simulation, record the highest pressure at each station's inlet and outlet water hammer pressure relief; (5) In turn, simulate the control logic triggered by all fault conditions in the control principle, and finally compare and select each station's water hammer relief valve The ultimate pressure at the pressure relief.

Table 2. The simulated ultimate pressure of the water hammer relief valve at each station entry and exit.

| Station name | Simulate ultimate pressure | Actual set pressure |
|--------------|---------------------------|---------------------|
|              | RL Out | MSLin | MS Out | BS In | BS Out | MD In | MD Out | AL In |
| Simulate ultimate pressure | 9.31  | 7.13  | 12.91  | 6.02  | 12.78  | 8.46  | 11.78  | 7.31  |
| Actual set pressure | 9.7   | 7.7   | 13.2   | 4.7   | 13.2   | 9.7   | 12.3   | 7.7   |

It can be concluded from Table 2 that the simulated limit pressure of BS station is 6.02MPa, while the actual set pressure is 4.7MPa. The suggested value of the set pressure at this point should be 6.3MPa. However, since the design pressure at this point is 5MPa, the discharge pressure is set as 5.2MPa after coordination.

3.3. Research on Response Time of Control Principle

Based on Table 1, the corresponding time of the control principle under different fault conditions is studied successively according to the following methods, and the relative optimal value is given. Mainly design the valve turn-off time and the corresponding time of the control logic under the fault.

3.3.1. Valve closing time. The valve switching time of the crude oil pipeline trunk line is 180s. This part mainly studies the value range of valve switching time based on different fault conditions and gives the suggested setting value.

The complete closing time interval of the valve under different working conditions is simulated successively. Taking the intersection of all the obtained valve closing time intervals, the value range of the valve closing time is 177-181s. In practice, the setting value is 180s, and it is suggested to set the full shutdown time of the valve as 178s, so as to ensure the advance protection of the pipeline by the protection program under the failure condition, and close the valve as soon as possible in the case of failure to reduce the loss.

3.3.2. Control the response time of the logic. In the control principle, it is clear that the response time of the control logic under fault conditions is 30s. This section mainly discusses whether it is reliable. When the control logic response time is 30s, the whole line can be triggered without overpressure under fault conditions. It is recommended that the response time can be appropriately reduced to avoid losses caused by fault conditions.

4. Conclusions

(1) Based on SPS software simulation results, there are two unreasonable control principles of the crude oil pipeline. One is that the setting value of the inbound water hammer pressure relief valve of the BS station is too low, and the setting value of the water hammer pressure relief valve should be changed to 6.3MPa; the other is the advance protection program error under the condition of the pump rejection of the MD station. The above two defects have been revised, so the reliability research of the control principle is very meaningful.

(2) Through the simulation of the response time of the control principle of the crude oil pipeline, the value range of valve turn-off time is 177-181s. It is recommended to set the valve full-off time to 178s; when the control logic response time is the 30s, the whole line can be triggered without overpressure under fault conditions. It is recommended that the response time can be appropriately reduced to avoid malfunctions. The loss was caused by the situation.
(3) After this reliability study, several control logic revisions have been completed, which is of great significance for improving the reliability of the control principle of the crude oil pipeline.

(4) The wall thickness of long-haul crude oil pipeline in the model is input by the wall thickness of design data, the checking result is only for clean long-haul crude oil pipeline. The operating unit shall reasonably arrange pigging operations according to the wax deposition of the crude oil pipeline to avoid the failure of the long-distance crude oil pipeline control principle caused by the wax deposition on the tank wall.

References

[1] Dong Youzhi, Wang Yuanlong, Liu Xingquan. Discussion on crude oil fully enclosed transportation process and safety measures [J]. Petrochemical technology, 2015, 22 (9): 26-27

[2] Yu Guanghui. Research on closed transportation and automatic process transformation of lunku Shanshan crude oil pipeline [J]. Oil and gas field surface engineering, 2018, 37 (4): 53-56

[3] Liu Bo, Teng Fei. Common problems and solutions of closed transportation of long-distance crude oil pipeline [J]. Petrochemical technology, 2019 (5)

[4] Tan Wei, Zhang Yanxia, Feng Shuyuan, et al. Water hammer pressure relief system of oil pipeline based on GB 50253 [J]. Modern chemical industry, 2015 (9): 195-196

[5] Huang Jingya, Liang Guangchuan, Zhou Jun. peak regulation analysis of gas transmission network based on SPS software [J]. Chemical management, 2017 (2)