Performance Analysis of Single-Disc and Multi-Disc Check Valve

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ABSTRACT

The check valve performs the function of protecting the pump from abnormal conditions in the piping system. The pressure variation caused by water hammer can be obtained using the Joukosky equation. The multi-disc check valve is closed by the weight of the main disc and the sub discs, so the bottleneck of the fluid outlets prevents water hammer. We reproduced the water hammer phenomenon in the constructed test equipment. The test confirmed that when the water hammer is applied to the check valve, the pressure of the multi-disc check valve rises less than that of the single-disc check valve. During the multiple-disc check valve test, there was no leakage in the leak test, the differential pressure was measured (0.02 ~ 0.18) bar in the pressure drop test, and the working pressure for the minimum working pressure test was measured at 0 bar.

1. INTRODUCTION

The check valve is one of the many valves used in the piping system. The valve opens when the fluid flows in the forward direction, and the valve is automatically closed to stop the flow when the fluid flows in the reverse direction. It is installed at the pump outlet of the piping system to protect the pump in an abnormal state. However, a water hammer phenomenon occurs, i.e. the sudden rise and fall of pressure when the check valve is closed due to its structure and operating principles. This water hammer phenomenon can be calculated using the Joukosky equation. In general, the check valves are divided into the swing-type check valve, which is closed immediately in case of backflow, the dashpot-type, tilting and non-slam check values, which are closed more slowly than the cycle of the water hammer phenomenon thus alleviating the water hammer. To ease the water hammer phenomenon occurring in the piping system, the aforementioned check valves must be used. These valves however, have common problems: i.e. as they use the hydraulic cylinder to close the disc, the product is heavy and voluminous, and the cylinder must be inspected and replaced periodically. They also have problems with installation. However, the multi-disk check valve, which is analyzed in this study, can alleviate the water hammer in a similar manner to the dashpot-type check valve, that is, the main disc is closed by its own weight, and then the sub discs are closed sequentially by their own weight. The authors will improve the reliability of the multi-disk check valve by comparing the performance of the multi-disc check valve and the single-disc check valve.

Table 1. Failure mode and mechanism

Main component	Function	Failure mode	Failure mechanism
Valve body	Maintaining the fluid passage / maintaining	Crack	Impact / cumulative fatigue
		Corrosion	Corrosion by moisture
		Packing out of position	Impact / cumulative fatigue
Valve cover	Coupling with the body / leak tightness	Crack	Impact / cumulative fatigue
Seat	Blocking the fluid flow / leak tightness	Wear	Cumulative fatigue
		Destruction	Impact
Multi-disc	Opening and closing the fluid flow	Crack	Impact / cumulative fatigue
		Deformation	Impact / cumulative fatigue
Valve side	Disc control	Destruction	Impact / cumulative fatigue
		Loose nut	Cumulative fatigue

2. RELIABILITY ANALYSIS OF MULTI-DISC CHECK VALVE

The field operating conditions of the check valve were investigated with the results showing that the main failures are the wear and destruction of the valve disc seat caused by the repetitive operation of the valve disk due to the fluid flow. This can be evaluated by the durability test that reproduces the water hammer. The multi-disc check valve looks the same as the swing-type check valve, but as illustrated in Figure 1, the main disc has many sub discs. Table 1 shows the failure modes and mechanisms of the multi-disc check valve.

The life span of the multi-disc check valve follows the Weibull distribution, and in consideration of the field conditions of the multi-disc check valve, the warranty life will have a confidence level of 70 %, and should guarantee B_5 life 7,200 cycles. The main failures are the wear and destruction of the disc seat due to the repeated operation of this disc and impact. As it is equivalent to the wear mentioned in "Machinery Failure Analysis and Troubleshooting," the shape parameter (β) will be 3.0. The zero-failure test time is calculated per equation (1).

$$t = B_{100p}\left(\frac{\ln(1-CL)}{n\ln(1-p)}\right)^{\frac{1}{\beta}}$$

$$= 7{,}200\left(\frac{\ln(1-0.7)}{4\ln(1-0.05)}\right)^{\frac{1}{3.0}} = 12{,}986.67 \cong 13{,}000 \qquad (1)$$

The basic performance evaluation items of the multi-disc check valve include the operation confirmation test, the minimum operating pressure test, the pressure drop test, the water hammer alleviation test, the internal leak test, and the external leak test.

3. RELIABILITY EQUIPMENT OF MULTI-DISC CHECK VALVE

The water hammer phenomenon occurs in the check valve of the piping system. Fluid is supplied normally by the pump in a waterway a few km long, and if the fluid supply is stopped due to the emergency stop of the pump, the supplied fluid moves backward due to the difference in the fluid heads and the inertia according to the closure of the check valve, thus the first water hammer occurs. When this shock wave moves forward and comes back, a second and third shock wave is generated. To reproduce this water hammer phenomenon, a waterway a few km in length is necessary, but as it is impossible to make a long waterway due to the limitations of the laboratory, the test equipment was implemented by installing a pressure tank in place of the long watercourse as illustrated in Figure 2.

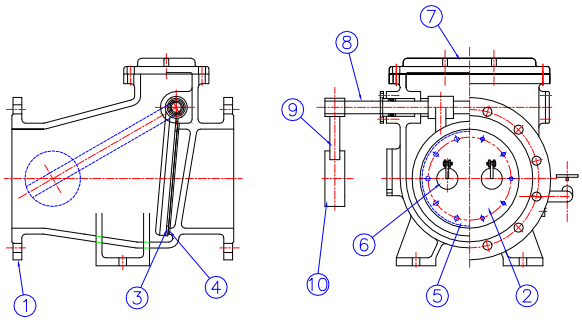


Figure 1. Structure of the multi-disc check valve

The durability of the check valve can be assessed by using the water hammer phenomenon, reproduced through this test equipment to generate big repeated shock waves (surge pressure or pick pressure).

The circuit diagram of the test equipment, which can conduct the basic performance test and the durability test, is as shown in Figure 2, and the actual test equipment is illustrated in Figure 3.

The fluid flows through the check valve, and the pressure tank is pressurized as shown in Figure 4. If the specified pressure is reached, the supplied fluid is discharged immediately from the inlet of the check valve through the auto valve operation. Then, the pressure applied to the pressure tank generates the water hammer at the outlet of the check valve. This is how the water hammer effect is generated using the test equipment.

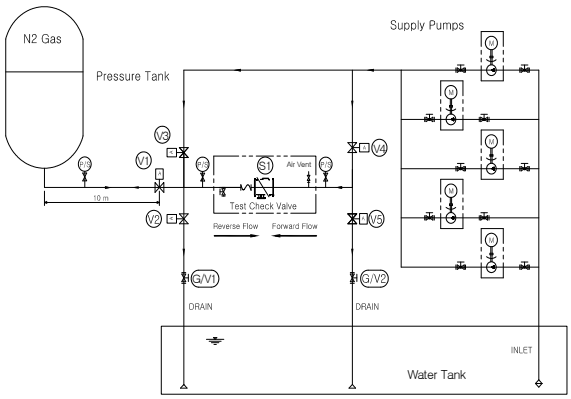
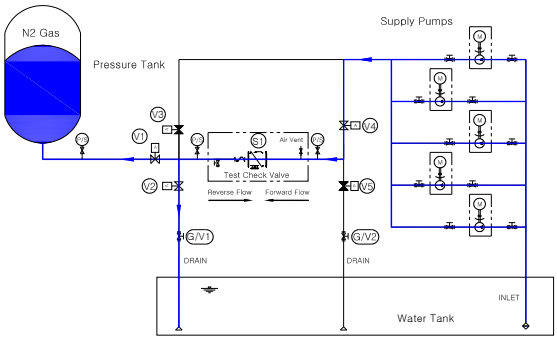
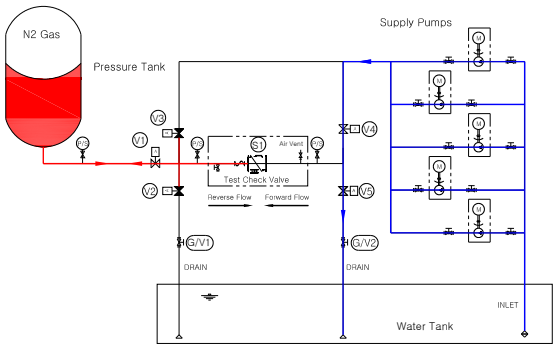


Figure 2. The circuit diagram of the testing equipment

Figure 3. Testing equipment

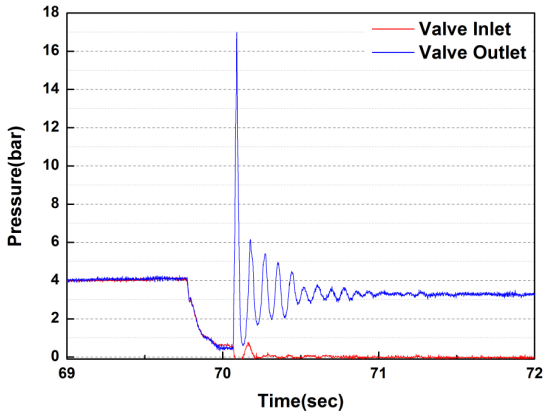


(a) Pressurizing the pressure tank

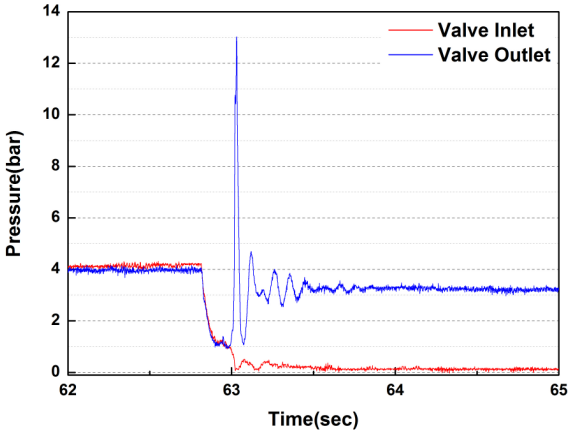


(b) The water hammer at the check valve

Figure 4. The principle of the occurrence of the water hammer in the testing equipment



(a) Single-disc check valve



(b) Multi-disc check valve

Figure 5. Comparison of the pressure rise due to the water hammer

4. RELIABILITY ASSESSMENT OF MULTI-DISC CHECK VALVE

The pressure rise in each check valve was observed as the water hammer was applied to the single-disc check valve and the multi-disc check valve through the test equipment. As illustrated in Figure 5, it was confirmed that the pressure of the single-disc check valve rose from 4 bar to 17 bar, with the pressure amplitude lasting for quite some time. In contrast, the pressure of the multi-disc check valve rose from 4 bar to 13 bar, and the pressure amplitude decreased more quickly than that of the single-disc check valve. It is believed that the water hammer pressure of the multi-disc check valve rises less, and the pressure amplitude quickly decreases because the water hammer is alleviated by the sub discs installed in the main disc.

The basic performance of the single-disc check valve and the multi-disc check valve was compared with the results showing that at each flow and pressure, the pressure drop was (0.11~0.16) bar for the single-disc check valve, and the pressure drop was (0.02~0.18) bar for the multi-disc check valve. The pressure drop was similar in both check valves, but when it comes to the minimum operating pressure test, the operating pressure of the single-disc check valve was 0.11 bar, while the pressure of the multi-disc check valve was 0 bar. As the fluid flows only when the main disc of the single-disc check valve is open, a little pressure was required to open the main disc, whereas the fluid flows when only the sub discs are open and almost no pressure is required in the case of the multi-disc check valve.

5. CONCLUSION

This study analyzed the reliability of the multi-disc check valve, and presented the evaluation items for the reliability of the check valve. The main failures of the check valve are the wear and destruction of the disc seat due to the repeated operation of the disc and impact. The check valve is directly exposed to the water hammer occurring in the actual piping system, and is damaged the most. Accordingly, in consideration of the environment of the laboratory, test equipment capable of reproducing the water hammer was implemented, and it was confirmed that the water hammer, similar to that which actually occurs in the field, takes place. This study also proposed a test method of using the repeated water hammer applied to the check valve to assess durability

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BIOGRAPHIES

Tae-Kook Park received his M.S. degree in mechanical engineering from Korea Maritime University in 1999. He is a senior researcher at the Reliability Assessment Center of the Korea Institute of Machinery & Materials, Korea. His research interests are heat exchanger, water valve and reliability research about machinery.