Failure Mechanism and Prevention Research of Adhesive Wear in the Guide Part of Globe Valve

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Abstract. For the failure of a low-temperature globe valve, through disassembly and material analysis, the cause of the failure was initially determined to be caused by adhesive wear between the disc guide rod and the valve seat. From the three aspects of material detection, stress and adhesive wear, the failure mechanism of stainless steel motion pair was analyzed. Finally, the wear test was carried out for chrome plating and non-chromium plating. Tests showed that when the valve seat is chrome-plated, the surface hardness of the guide portion is increased, which could effectively prevent the adhesive wear failure of the guide rod and the valve seat guide hole.

1. Introduction

With the development of modern technology, cryogenic liquids such as liquid hydrogen and liquid oxygen have been widely used, and a large number of cryogenic valves are required for the production, transportation and storage of cryogenic liquids [1-2]. The reliability of the valve is particularly important, which directly affects the smooth progress of production and transportation. It requires extensive simulation and testing to ensure reliability and safety in the design, production and use of the product [3-6].

A low-temperature globe valve is widely used in a liquid hydrogen production and conveying system. In an important test operation, when the valve was pneumatically opened, an abnormal sound was emitted internally. When the operator switched to manual operation, the valve still could not be opened. In this paper, through the fault tree analysis, the fault was located at the guide part, which was caused by the adhesive wear failure. Tests were carried out to verify the failure mechanism and provide a basis for improving the reliability of the low temperature globe valve.

2. Low temperature globe valve failure

This type of globe valve is mainly composed of actuator, spool assembly, valve disc and valve seat, and adopts manual and pneumatic control modes (as shown in Figure 1). The disc guide rod moves down the center line of the valve seat to achieve valve action. When the disc sealing surface is in close contact with the seat sealing surface, fluid is prevented from passing and the valve is completely closed. Combined with the structural characteristics of the valve and the use of the whole life cycle, the cause of the valve stuck was analyzed.

1) The Pneumatic actuators are mainly composed of lower valve stem, cylinder, piston, upper valve stem, air travel, connecting section and other parts. After the fault occurs, the disassembly revealed that the actuator has no wear and the size meets the requirements, and the malfunction of the moving
parts of the actuator can be eliminated. After reinstalling the actuator, manual operation was performed, and the valve opening height was stuck at 20 mm (design height is 35 mm).

2) The valve core assembly is composed of a valve stem, a bellows, an insulating sleeve and the like. For the analysis of moving parts, except for the bellows, which are separate moving parts, the other moving parts are made of stainless steel material and aluminum bronze material, which has good wear resistance. And the valve worked normally in the early installation and use. Therefore, it is possible to eliminate the size difference of the spool assembly and cause this malfunction.

3) The valve disc and the valve seat movement pair are mainly composed of a valve flap, a valve guide rod, a guide sleeve, a valve seat and a bolt. Reviewed the production record of the valve, no substitute material. The parts were processed and the dimensions were satisfactory. The factory test met the design requirements. Moreover, the valve worked normally in the early stage, which could eliminate the machining size error and the excess of the guide surface to cause this failure.

Aiming at the internal faults of wear and deformation of valve core assembly, and the wear between the disc and the seat, the valve was dismantled and inspected destructively.

The inspection found that the valve core and the valve disc can be freely rotated under the pin connection without jamming; the disc guide rod and the valve seat guide hole were stuck, and the surface material of the part was obviously worn and abraded (as shown in Figure 2). Adhesive wear occurred between the disc and the seat.

3. Wear failure mechanism analysis

3.1. Adhesive wear

Adhesive wear refers to a form of wear in which the metal is adhered locally on the contact surface during sliding friction and the adhesion is broken during relative sliding. When the strength of the bonding point is larger than the shear strength of the friction pair material, and the bonding area is large, the mating surface of the moving part will wear and wear until the seizure occurs [7-9]. There are two main factors that affect adhesive wear.

1) Material characteristics: The greater the plasticity of the material, the weaker the ability to resist adhesive wear; the friction pair composed of a material having a high mutual solubility tends to adhere.

2) Contact stress: When the moving speed is constant, the amount of adhesive wear increases as the contact pressure increases. When the contact pressure exceeds 1/3 of the hardness of the material, the amount of adhesive wear increases sharply, and in severe cases, seizure occurs [7].
3.2. Material analysis

Valve material analysis was performed, including inspection of deposits on the valve guide bore, valve guide rod material, and seat material.

Table 1. Testing Sample Information.

| Inspection Number | Accumulations(1) | Guide rod(2) | Valve seat(3) |
|-------------------|------------------|--------------|--------------|
| Photographs in kind | ![Photograph](image1) | ![Photograph](image2) | ![Photograph](image3) |

The test results showed that the composition of the three sample materials is basically the same, and the metal scrap energy spectrum is shown in Figure 3. The valve flap and valve seat of the globe valve are made of 0Cr18Ni9 with good plasticity and toughness. The valve disc and the valve seat have the same hardness and are completely miscible friction pairs. During the sliding friction process, cold welding is easily formed between the same material molecules to meet the material conditions for adhesive wear.

![Spectrogram 1](image4)

Figure 3. The Energy Spectrum of Metal Scraps.

3.3. Contact Stress Analysis

According to the design drawings, a two-dimensional model was drawn (as shown in Figure 4). The simulation results showed that under the action of gravity, there was an angle between the center line of valve disc and the center line of valve core, which resulted in the sliding friction of cylinder force and gravity force in the normal direction.
The deflection angle $\alpha$ of the valve flap relative to the valve seat depends mainly on the guide length and the guide gap. The sinking deflection angle $\beta$ of the valve flap relative to the stem axis depends on the distance $L_1$ from the top surface of the valve flap to the effective length of the valve seat guide hole, and the clearance between the valve flap and the valve stem. The sinking deflection compensation angle $\theta = \alpha + \beta$ is compensated by $\alpha$ and $\beta$ only when the gap is 0.31 mm and the valve is fully open ($\theta \geq \gamma$). In the remaining motion state, the stem deflection cannot be compensated by $\alpha$ and $\beta$, and the disc guide rod and the valve seat guide hole will be in asymmetrical contact (the critical point angle is about $1.18^\circ$).

According to the size of the valve core, valve disc and other components, the contact point was simplified to the simple beam form. The equilibrium equation was used to find the reaction force of the two points of A and B respectively, and the mechanical analysis of the sinking deflection was carried out. When the valve was actuated, the deflection angle could not be compensated when $F_A=2242N$, $F_B=2342N$.

The simulation was carried out according to the gap range of the disc guide rod and the valve seat guide hole of 0.2 mm to 0.31 mm. The simulation results show that the maximum contact stress generated by friction on the metal substrate is about 1192.8 bar, which is greater than 1/3 of the hardness value of 0Cr18Ni9, that is, 620 bar, which satisfies the condition of adhesive wear contact stress.

In summary, since the disc guide rod and the valve seat were made of stainless steel 0Cr18Ni9, the hardness was the same and the adhesion was strong. In addition, due to the small motion gap and the presence of contact stress, the plastic deformation of the material caused the gap to become smaller, the adhesive wear range increases, and the heat generated by the friction increased sharply, causing local seizure.

4. Wear verification and prevention test
The review found that there was a valve with an chrome-plated valve that also showed adhesive wear. The remaining chrome-plated valves did not wear out. According to the valve use environment, a
valve test verification system was built (shown in Figure 7), to test the two valves of chrome plated valve and non-chrome plated valve. The test process is as follows.

1) Confirm the size and status of the valve and record the data.
2) Assemble the valve to confirm that the action and sealing are good.
3) Supply compressed air to the valve and observe the inlet pressure gauge. When the pressure is 0.4MPa, the valve is pneumatically opened to exhaust. The exhaust volume is controlled by the exhaust port plugging, and the time at which the pressure at the inlet end of the valve is reduced from 4 bar to 2 bar is controlled at about 2 min. Observe the inlet end pressure gauge and pneumatically close the valve exhaust to 0.2MPa.
4) After 20 repetitions of steps 3), the valve is decomposed to take out the disc, measure the size, check the status and record the data.
5) Repeat steps 2), 3), and 4) for a total of 100 times.

First, the chrome plated valve was tested. After 20, 40, 60, 80, and 100 motion tests, the valve was disassembled and the disc guide rod was dimensioned. After inspection, every 20 strokes, the surface of the valve flap was not scratched, and the size was the same as before the test.

Replace the non-chrome plated disc and continue the test. The inspection found that after 20 or 40 movements, there was no obvious scratch on the moving part of the disc guide rod; after 60 movements, the disc guide rod was obviously scratched in both directions (as shown in Figure 9). After 80 movements, the flap guide rod is scratched and aggravated (as shown in Figure 10). In addition, the seat guide surface is also subject to wear and scratches.
It can be seen from the wear test that after the chrome-plated valve flap is repeatedly actuated, the contact surface of the guide rod is scratched, and the phenomenon is the same as this failure. After the valve disc is chrome-plated, the hardness of the chrome layer is greatly increased, and the stress generated by the friction on the metal substrate is less than the stress causing the adhesive wear. After multiple actions under the same working conditions, the guide surface did not appear scratched.

5. Summary
The disc and seat parts of the low-temperature globe valve were both 304 stainless steel. Under the action of gravity and cylinder force, the disc guide rod and the valve seat guide hole were repeatedly rubbed to form adhesive wear, which caused the valve to be stuck. By increasing the surface hardness after chrome plating on the guide bar, the occurrence of adhesive wear can be effectively avoided, and the valve is prevented from being seriously worn and caused to be stuck.

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