Sealing selection for pumped storage unit ball valve seals

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Abstract: This paper introduces the structure and working principle of the inlet ball valves for the Phase II units of Guangzhou Pumped Storage Hydropower Plant, as well as the issues of damage to the upstream and downstream sealing rings since the units were put into operation. The causes of the problems are analyzed from several aspects, including the material and structure of the sealing rings and the daily operating conditions. The paper focuses on the research of sealing selection and the effects after the retrofitting.

Keywords: Sealing rings, Internal leakage, Sealing selection

1. Introduction

Guangzhou Pumped Storage Hydropower Plant (hereinafter referred to as Guangxu) is located in Cong Hua District, Guangzhou City, Guangdong Province. The entire power station is constructed in two phases. Phase I and Phase II each installed four 300MW reversible pumped storage units, with a single-unit capacity(in power generation mode)of 300MW and a total installed capacity of 2400MW.Phase I(referred to as Plant A)was fully completed in 1994,with the four units named Units 1 to 4.Phase II(referred to as Plant B)was fully completed in 1999,with the four units named Units 5 to 8.Both Phase I and Phase II projects were put into operation in March 2000.After the commissioning of the eight 300MW units, Guangxu has become the largest pumped storage power plant in the world today.

2. The function of the ball valves in plant B

Reversible pumped storage units are highly flexible and convenient to start and stop. They generate electricity by releasing water during peak grid load periods and use excess electrical energy to pump water during off-peak periods. This plays an active role in peak shaving and valley filling in the power grid, making the load of various power stations in the system more uniform and improving the economic operation of the entire power system.

Guangxu Hydropower Station is a large-scale pumped storage power station with a high head, long water conveyance pipelines, and a water diversion scheme of one tunnel for four units. Ball valves must be installed before the turbine scroll case, and their functions are as follows:

To open or close the ball valve during startup or shutdown to allow or block the flow of water.

To isolate the unit from the upstream waterway during maintenance, ensuring safe maintenance and the normal operation of other units.

To close the ball valve in the event of a unit failure to cut off the water flow and prevent runaway accidents.

In the initial stage of commissioning, to serve as a quick closure device for the pressure steel pipes of units that have not yet been commissioned, ensuring the safety of the powerhouse.

3. Structure of the ball valves in plant B

The ball valve is a horizontal-axis, dual-seal structure, mainly consisting of the valve body, actuator and lever arm, extension pipe and expansion joint, valve core, shaft neck and bearing, and upstream and downstream seals.

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The upstream and downstream seals are composed of movable sealing rings embedded in the inner cavity of the valve body and the fixed sealing rings on the adjacent valve core. When the ball valve is closed, the pressure generated by the water from the upstream steel pipe causes the stainless steel movable sealing ring to slide on the aluminum bronze surface embedded in the valve body, allowing it to contact or separate from the fixed sealing ring, thereby achieving the purpose of engaging or disengaging the seal.

There is a set of seals on both the upstream and downstream sides of the ball valve. The upstream seal is a maintenance seal, manually engaged and disengaged, and equipped with a mechanical locking device. Its functions are:

When maintenance of the downstream seal or the valve core shaft seal is required, the upstream seal and its locking device can be engaged without the need to drain the upstream waterway.

When maintenance of the unit's rotating parts is needed or when access to the draft tube is required, the upstream seal and mechanical lock can be engaged as a safety isolation measure.

The downstream seal is a working seal, operated automatically by hydraulic means. Its function is to seal the upstream waterway and prevent water leakage when the unit is shut down and the ball valve is closed, thereby reducing water loss.

4. Equipment condition and existing issues

When the units of Guangxu Plant B were commissioned, the upstream sealing rings of the ball valves were originally designed by the manufacturer to use an O-ring Chem-ring structure(i.e., a PTFE-coated O-ring, composed of a silicone or Viton core and a relatively thin outer layer of Teflon PFA).The purpose of this sealing arrangement was to form a sealing chamber for the upstream seal, enabling hydraulic control of the engagement and disengagement of the upstream seal.

However, the O-ring Chem-ring structure seal selected at the time of construction has proven to have an unstable service life. During the initial installation of the units (in 2000), an incident occurred with Unit 8's ball valve, where the seal broke, necessitating the draining of the upstream waterway for inspection and replacement. In 2003, during the epoxy maintenance of the upstream waterway in Plant B, the upstream sealing rings of Units 5 and 6 were replaced. In November 2014, during operation, Units 6 and 8 were found to have water leakage in the upstream sealing rings of the ball valves. This indicates that the service life of the seal is unpredictable, with some failing immediately during installation, others lasting 11 years before leakage, and even some remaining intact after 15 years of use.

Analysis of the issue reveals that the sealing environment can be categorized into static and dynamic sealing conditions, with dynamic sealing further divided into rotational and reciprocating motion along the axis. It is determined that the upstream sealing rings of the Guangxu ball valves operate in a reciprocating motion along the axis, which is a dynamic sealing environment. Further analysis shows that the O-ring Chem-ring structure, with its circular cross-section, has poor structural stability within the square sealing groove. This makes it prone to local twisting during reciprocating motion along the axis. Mild twisting can cause uneven pressure and wear, leading to water leakage, while severe twisting beyond its elastic recovery limit can result in stretching and breaking at the twisted section. The occurrence and severity of twisting are random events, which explains the unpredictable service life of the seal.

In summary, the O-ring Chem-ring structure seal currently used in Plant B has design flaws, and its unpredictable service life has led to the aforementioned failures and water leakage. Therefore, it is necessary to retrofit the structure of the upstream sealing rings of the ball valves in Plant B and improve the sealing material to achieve a longer and more stable service life for the seals.

5. Selection and design

After a thorough selection analysis, it is planned to use H-ECOPUR (oil-resistant, water- resistant, and wear-resistant polyurethane) as the sealing material and adopt a special D-shaped sealing structure form GK35-PH to implement the technical retrofit of the upstream sealing rings of the ball valves. The feasibility discussion is as follows:

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5.1. Comparison of sealing structure types

Common types of dynamic sealing structures for ball valve movable rings are shown in Figure 1. This retrofit plan will use sealing structure(c)to implement the retrofit.

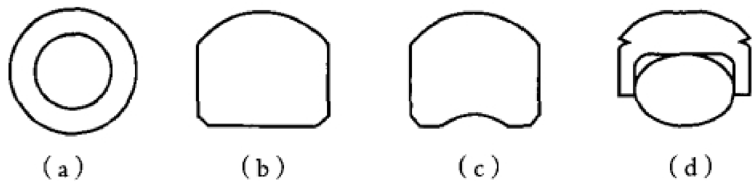

Figure 1 Common Dynamic Sealing Forms for Ball Valve Movable Rings:
(a)Chem-ring Structure;
(b)D-shaped Seal;
(c)Special D-shaped Seal;
(d)Composite Seal

The sealing structure(a)is the original sealing structure used in Plant B, and the same structure was also used in Tian Huang ping Pumped Storage before its retrofit. The O-ring sealing structure has good compressibility and sealing performance when used as a static seal; however, it is not suitable for use as a dynamic seal.

The sealing structure(b)was widely applied in the design of many pumped storage power stations from the 1990s to the early 21st century, such as Guangxu Plant A, Hui stores, and Qing stores. The D-shaped seal fits perfectly with the installation groove, providing geometrical stability and thus the ability to resist twisting. However, this structure has the disadvantage of having a small allowable wear amount (the bottom of the D-shape fills the sealing groove completely, leaving no space for compression). Once the interference fit at the head of the D-shape is worn away, leakage will occur.

The sealing structure(c)has been applied in the design of many pumped storage power stations since the 21st century, including those with a conical top. Examples include Pu yang River Pumped Storage, Xian Ju Pumped Storage, Hui Long Pumped Storage, and Tian Huang ping Pumped Storage after its technical retrofit. This structure is an improved version of the D-shaped seal, inheriting its ability to resist twisting. Additionally, because it reserves space at the bottom for compression and rebound, this sealing structure can rely not only on its own interference fit but also on its elasticity for compensation, thereby extending the service life of the seal.

The sealing structure(d)is also widely used in many pumped storage power stations today. The upper part is a butterfly-shaped structure (or rectangular, etc.), while the main body is similar to a D-shape, inheriting the ability to resist twisting. The lower part features an O-ring seal (usually made of nitrile material) to provide better elastic compensation, resulting in a longer expected service life for the seal. However, since the sealing structure(d)is a composite structure, it requires a deeper sealing installation groove in the movable ring. The sealing installation groove in Guangxu's movable ring is designed to be relatively shallow. If the sealing structure(d)were to be used, it would be necessary to deepen the installation groove by at least 2.5 mm according to estimates. This would leave only 32 mm at the thinnest part of the movable ring, reducing its overall strength and resistance to deformation. This solution would require structural changes to the main equipment, which could have a significant impact on the stable operation of the equipment.

In summary, with the development and practical experience in the hydropower industry, and referring to the gradual retrofit and improvement of ball valve movable ring sealing technology in hydropower stations, the sealing structure(c)is currently the most rational and suitable for the retrofit needs of Guangxu.

5.2. Comparison of sealing material parameters

Common dynamic sealing materials for ball valve movable rings can be categorized into three types: PTFE-coated O-rings, nitrile rubber, and polyurethane. The H-ECOPUR (oil-resistant, water-resistant, and wear-resistant polyurethane) sealing material planned for this retrofit was jointly developed by two foreign

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companies specifically for the characteristics of hydropower equipment and is manufactured by one of the original factories. It is a polyurethane sealing material specifically designed for the main inlet valves of hydropower stations, with the initial intention of replacing rubber seals in hydropower facilities. A comparison of the performance of these sealing materials is shown in Table 1.

Since the water temperature at Guangxu ranges from 16 to 35℃and is alkaline, the thermal and chemical resistance properties of the above materials all meet the usage requirements. The focus is on comparing their mechanical properties. As a composite sealing material, the PTFE-coated O-ring has performance characteristics between nitrile rubber and fluororubber.

From the parameter comparison in the table, it is evident that the material properties of H-ECOPUR polyurethane are comprehensively superior to those of PTFE-coated O-rings and nitrile rubber. Specifically:

High tensile strength and elongation at break. When used as a dynamic seal, this material is less likely to be flipped or twisted and broken.

High tear strength. The contact surface of the seal made from this material is less prone to delamination due to shear forces from friction, ensuring stable service life.

High elastic recovery rate. The seal performs well, and it can rebound according to the subtle dimensional changes of the sealing groove when sliding inside it. This ensures a good compression allowance is maintained throughout the dynamic sealing groove.

Low wear volume. That is, it has a low coefficient of friction. The starting pressure of this sealing material is low, and it is less likely to adhere to the mating metal surfaces. After a long period of inactivity, it will not tear or delaminate locally when it moves again due to adhesion to the fixed parts. It is particularly suitable for the upstream seal of ball valves, which are in a state of long-term inactivity with occasional movement. Moreover, low wear volume will inevitably lead to an extended design service life.

Table 1:H-ECOPUR vs. Nitrile& Fluororubber Performance Comparison

Performance		Test Method (DIN)	Unit	Nitrile Rubber	Fluororubber	H-ECOPUR Polyurethanes	Remarks
Thermal Properties	Maximum Operating Temperature	/	℃	100	200	110	Water Temp.:16-35℃
	Minimum Operating Temperature	/	℃	-30	-20	-30	
Mechanical Properties	Tensile Strength	53504	MPa	16	8	50	
	Elongation at Break	53504	%	130	200	330	
	Tear Strength	53515	N/mm	20	21	100	
	Elastic Recovery Rate	53512	%	28	7	29	
	Wear Volume	53516	mm^3	90	150	17	
Chemical Resistance Properties	Resistance to Dilute Alkali	/	/	B	B	B	Lower water is weakly alkaline
	Resistance to Hot Water	/	/	C	B	B	

6. Operation after retrofit

The ball valve systems of the four units in Plant B of Guangxu were overhauled in December 2015, using the H-ECOPUR (water-resistant, wear-resistant polyurethane) sealing material and the special D-shaped

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sealing structure GK35-PH. The technical retrofit of the upstream and downstream sealing rings of the ball valves was implemented. In actual operation, no water leakage was found during the pressure test of the movable ring engagement and disengagement chamber. The engagement and disengagement of the upstream and downstream seals were smooth during the tests, and the ball valve seals operated normally during unit commissioning, with good overall equipment performance.

7. Conclusion

From the above selection and retrofit, we have concluded two important points that should be given sufficient attention in the design of the upstream and downstream sealing rings of the inlet ball valves for large hydropower units:

It is essential to select sealing materials with good water resistance and wear resistance.

It is crucial to choose a superior sealing structure.

Through continuous exploration and effort, Guangxu has improved the upstream and downstream sealing rings of Plant B's ball valves and achieved certain results. It is hoped that this paper can provide a reference for the inlet ball valve design of hydropower units under construction or to be built.

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