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Underwater Access Door System for Tidal Power Generation

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Abstract

The difficulty in maintaining tidal power generation equipment is an important factor restricting its development. The tidal power underwater access door system uses a power device to drive the metal seal. When the machine is stopped, a temporary channel is formed between the rotating and stationary parts. After drainage, personnel can maintain the rotating parts through the channel. In the past four years of use, the system has good stability and zero leakage, solving the problem of having to pull out of the sea for maintenance of tidal power generation equipment and reducing maintenance costs.

Keywords: difficult to maintain, temporary access, good stability, zero leakage

1. Introduction

As a green and renewable energy source, tidal energy has stronger stability and predictability compared to wind and solar power [1,2]. Due to the much higher density of water than air, the diameter of blades is much smaller than that of wind power under the same power conditions, and the manufacturing cost is cheaper. Therefore, countries around the world strongly support tidal energy in terms of economy, policies, and other aspects [3,4]. The UK has even launched CFD electricity pricing for this, leading the world. There are three main forms of mainstream power generation: floating, sunken, and pile up. After years of development and continuous technological progress, the single unit power has reached the megawatt level from tens of kilowatts, and the power generation efficiency has gradually improved. The cost of electricity per kilowatt hour has been continuously reduced, and it is expected to surpass wind and thermal power in the near future. but many problems have also been exposed. One of the challenges is that due to the fact that the vast majority of power generation equipment is located below sea level, the entire power generation equipment must be lifted out of the sea during maintenance, which is expensive and time-consuming, restricting the development of the entire industry.

2. Working Principle

The LHD tidal energy megawatt scale project in China is located in the Zhoushan Islands, with a maximum seawater velocity of 4.5m/s and a sediment content of approximately 0.12kg/m3, an underwater access door system (Figure 1) is adopted. The tidal energy underwater access door system uses a power device to drive the metal seal. When the machine is stopped, a temporary channel is formed between the rotating component A and the stationary component B. After drainage, personnel can maintain the rotating component through the channel. In the past four years of use, the system has good stability and zero leakage, solving the problem of having to pull out of the sea for maintenance of tidal power generation equipment and reducing maintenance costs.

3. Systems Design

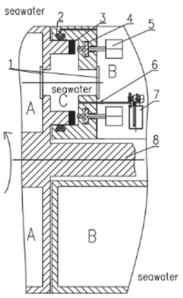

Figure 1. System schematic diagram

As shown in Figure 1, the system mainly consists of 1 A/B cabin access door, 2 maintenance seals, 3 rubber seals, 4 metal seals, 5 hydraulic system, 6 valves, 7 drainage system, 8 main shaft and other components. When the rotating cabin A needs maintenance, the generator set enters maintenance mode, and the main shaft (8) gradually stops rotating. After aligning the pointer on the main shaft with a specific angle, the brake is applied, and the positioning pin is inserted to align the cabin doors A and B (within an angle deviation of 0.2 °); The hydraulic system (5) drives the metal seal (4) to be in close contact with the rubber seal (3), and the stroke is confirmed by displacement sensors. The hydraulic lock can prevent the metal seal (4) from separating from the rubber seal (3) in case of sudden power failure. The mechanical lock can prevent danger in case of oil pipe rupture in the hydraulic system (5). At the same time, a synchronization system is added to improve the consistency of the hydraulic system operation and avoid equipment damage caused by jamming due to unsynchronization; At this point, a temporary channel will be formed at point C to isolate it from the external seawater. Valve (6) will be opened to discharge the seawater from point C through the drainage system (7), according to the volume of the temporary channel, it can be calculated that when all the seawater is discharged, the level gauge in the drainage system (7) will rise by about 350mm to determine whether all the seawater in the temporary channel has been discharged. There are two types of level gauges: pressure level gauge and ultrasonic level gauge. When the difference between the two values is within 10mm, it is judged that both are in good condition. The average of the two values is used as the high and low level to start and stop the drainage system. When the two values exceed 10mm, an alarm is triggered and personnel need to immediately inspect and replace the damaged level gauge. The drainage system needs to be independently powered (separate from the main control system, and can also be powered in a stopped state), and there is a backup power supply. The drainage system can be started in the event of an external power outage to avoid Occurrence of danger; Then open the entrance door of cabin B, clean up the sludge and debris in the temporary passage to prevent them from entering cabin A. Open the entrance door of cabin A, clean the sealant at the entrance door, and personnel can enter cabin A with tools for maintenance and repair (pay attention to locking the two entrance doors to avoid accidental closure and endangering the staff).

After maintenance is completed, replace the sealing strip of the entrance door of cabin A, apply sealant on the end face, and apply locking glue on the fixing bolt thread to separate the thread from seawater, reduce corrosion rate, and increase bolt service life. After the glue dries, close the entrance door of cabin B (1), remove the mechanical lock, and the hydraulic system (5) drives the metal seal (4) to detach from the rubber seal (3). Close the valve (6), remove the main shaft positioning pin, and the unit can start normal power generation.

Due to the possibility of damage to the rubber seal (3) during operation, when replacing it, fill the maintenance seal (2) with 0.3MPa gas(determined by experiments), drain it, and open the doors B and A to replace the rubber seal (3) at point C, thereby increasing the service life of the entire system.

According to the size of the human body and the possible maintenance tools, the inner diameter of the access doors at cabin A and B is set to 450mm, and the water depth at the access door is about 20m. The safety factor is taken as 1.5, and the thrust of the hydraulic system can be calculated as 4.75t. Under the premise of safety, based on the existing equipment, a hydraulic cylinder pressure of 8Mpa is selected. The hydraulic system consists of two hydraulic cylinders, each with a diameter of 60mm and a stroke of 50mm, and is driven in both directions.

During actual operation, when the main shaft (8) is excessively deflected, it can cause gaps between the metal seal (4) and the rubber seal (3), resulting in water leakage and system failure.

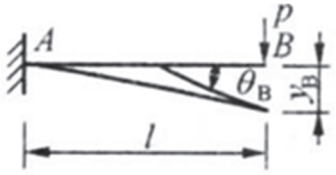

Figure 2. Cantilever beam

$$\text{Deflection} \quad y_B = -\frac{Pl^3}{3EI} \tag{1}$$

$$\text{Turning angle} \quad \theta_B = -\frac{Pl^2}{2EI} \tag{2}$$

Table 1. Parameter Table

P (N)	E (MPa)	I (mm4)
150000	$2.1*10^5$	$1.2*10^{10}$

The calculated deflection y_B is 0.23mm and the turning angle θ_B is 0.016 °. The rubber seal can meet the requirements [5].

The maximum operating condition of the generator set is when the unit is in runaway, and the unbalanced force at this time is calculated by the professional software Blade as follows, P=600000N, The calculated deflection is y_B is 0.92mm.

The gap between the rotating A cabin and the stationary B cabin is 14mm, mainly to ensure that the A cabin and B cabin do not collide during the operation of the generator set; At the same time, consider that large wooden sticks, cables, and other debris will not enter to avoid getting stuck or damaging the seals; We also considered the influence of marine organisms such as barnacles attached. The size of barnacles is generally larger than 20mm, and a gap of 14mm can effectively remove most barnacles. Without entering the door, a hydraulic system can be used to push out the metal seal to prevent barnacles and other marine organisms from attaching, which can effectively protect the seal and increase the service life of the entire system.

It is particularly necessary to design a system that includes a water leakage alarm system, wireless signal transmission, and remote control in order to monitor in real time whether there is water leakage in these parts during the power generation of the unit and take measures to prevent potential damage in the first time. Select a highly sensitive and corrosion-resistant water conductivity sensor and install it at the metal sealed shaft sleeve of cabin B to ensure that the sensor can detect the presence of water at the first time. And strict waterproof treatment should be carried out on the sensors and their connecting wires to prevent false alarms or damage caused by external environment. Choose the appropriate wireless communication technology NB IoT to ensure stable and reliable signal transmission. Adopting standard data transmission protocols to ensure the integrity and security of data during transmission. Use long-lasting batteries to provide stable power for wireless transmission modules. Set up a data receiving unit in the pitch shaft cabinet to receive leakage water signals from the wireless transmission module, and perform preliminary data processing and analysis. The processed data is promptly transmitted to the control cabinet, and control logic is written in the engine room pitch control cabinet. When a leakage water alarm signal is received, the shutdown program is automatically triggered and the corresponding alarm mechanism (sound and light alarm and SMS notification) is activated. At the same time, there is an independent power supply emergency drainage system at the bottom of cabin B, which can urgently drain the water leaked into the cabin in case of water leakage, avoiding damage to the equipment in the cabin. The power supply system has a battery as a backup power source, and the entire cabin at sea level will not be short circuit due to water leakage in cabin B, which will cause the emergency drainage system to fail.

4. Test of the Underwater Access Door System

The highest tide level in the sea area where the power generation equipment is located is 6 meters above the horizontal plane, and the lowest tide level is 3 meters below the horizontal plane, which means that the actual operating depth of the entrance system is 10-20 meters.

In order to ensure the reliability of the system, after the design and production are completed, installation tests are carried out in the factory using pressure instead of the depth of seawater. The operation is carried out according to the steps in the working principle, with pressures of 1 bar, 1.5 bar, and 2 bar respectively. The hydraulic system is repeatedly used to push out the metal seal, open and close the A and B cabin access doors, completely clean the water in the temporary passage, wait for 2 hours, and record the results after multiple tests.

Figure 3. Experimental Process 1

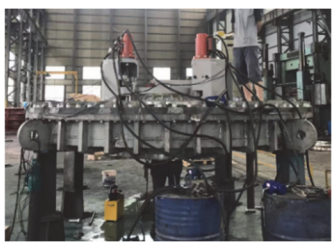

Figure 4. Experimental Process 2

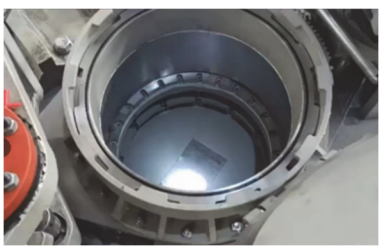

Figure 5. Result

Table 2. Test results

Pressure (bar)	Sand content (kg/m3)	Displacement sensor stroke1 (mm)	Displacement sensor stroke2 (mm)	Time (h)	Result
1	0.12	14.1	14	2	Without leakage
1.5	0.12	14	14	2	Without leakage
2	0.12	13.9	14.1	2	Without leakage

From the experimental results, it can be seen that the synchronization of the underwater access door system of the tidal power generation equipment is good at depths of 10 meters to 20 meters, and there is no jamming. The overall operation is good and there is no leakage; At the same time, under a driving pressure of 8Mpa, when the hydraulic system pushes out and retracts the metal seal, the overall stroke is within 2.5 seconds, and there is no occurrence of hard contact or loud noise caused by rapid speed.

5. Actual Operation

5.1 Installation, Debugging, and Use

After the experiment is completed, the underwater access door system of the tidal power generation equipment is installed on the generator set. After the generator set is lifted into the platform, debugging and grid connected power generation begin.

Figure 6. Entering process 1

Figure 7. Entering process 2

Figure 8. Entering process 3

Since its operation in January 2022, the system has been turned on about 70 times, and the overall operating condition is good with no water leakage, as shown in Figures 6, 7, 8 and Table 3.

Table 3. Opening time and frequency

Time	opening times	Average opening time (h)	running state
2022	22	5.2	Well, no leakage
2023	17	3.1	Well, no leakage
2024	19	6.7	Well, no leakage
2025	8	4.5	Well, no leakage

5.2 Existing Problems and Solutions

Due to the high sediment content in the local seawater and the presence of debris such as wooden sticks, it has not been used for a long time, resulting in people entering the door

The drainage pipe is blocked and unable to drain properly. Use iron wire to slowly remove debris before resuming normal use.

Under normal circumstances, the corrosion rate of carbon steel in seawater is about 0.05-0.15mm/yr. After 2 years of operation, in early 2024, it was discovered that the welding joint between duplex stainless steel SAF2507 and

carbon steel had severe corrosion, with a pit depth of about 5mm and a length of 70mm, far exceeding that of only carbon steel. Moreover, the corrosion was more severe in sharp areas than in flat areas, while duplex stainless steel SAF2507 had almost no corrosion, as shown in Figures 9 and 10.

Figure 9. Running for 2 years (sharp points)

Figure 10. Running for 2 years

After analysis, it is believed that the primary battery composed of duplex stainless steel SAF2507, carbon steel, and electrolyte seawater caused electrochemical corrosion [6], greatly accelerating the corrosion of carbon steel. At the same time, due to the phenomenon of discharge at the tip [7], the corrosion in sharp areas is more severe than in other areas. The solution is to apply a protective coating near the welding area (Figure 10) to isolate them from seawater and prevent electrochemical corrosion, thereby reducing the corrosion of carbon steel [8]. When operating, it is necessary to first clean the sediment and iron filings in the corroded area, then apply quick drying glue, and wait until it is completely dry before retracting the temporary channel. After one year of operation after repair, no corrosion phenomenon was found (Figure 12). Another way is to sacrifice the anode and zinc block for this type of welding, which can avoid corrosion of carbon steel. However, it needs to be welded in advance during installation in the factory. Currently, the space here is narrow and there are many electrical equipment, making it unsuitable for welding.

Figure 11. After repair

Figure 12. Run for one year after repair

6. Summary

After more than three years of use, the system has good stability and zero leakage. Maintenance personnel can carry out maintenance and repair operations inside the cabin, solving the problem of having to pull out of the sea for the maintenance and repair of tidal power generation equipment in the past, reducing operation and maintenance costs, and having high economic value, which helps to promote the development of the entire industry.

Regularly drain and sand to keep the drainage system unobstructed.

Without entering the door, use a hydraulic system to push out the metal seal to prevent the attachment of sea creatures such as barnacles and increase the service life of the system[9].

There is pointed discharge and electrochemical corrosion [10]between duplex stainless steel SAF2507 and carbon steel, and the contact surface corrodes quickly, requiring regular repair and protective coating [11,12].

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