Research on Vibration Failure Mechanism of High Pressure Pump in Reverse Osmosis Water Generator

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Abstract. Compared with other methods, the reverse osmosis method has the characteristics of simple equipment, convenient operation, high efficiency, no phase change, no heating, low energy consumption, low operating cost, strong adaptability and wide application range. It is the most promising seawater desalination technology. The high-pressure pump in the reverse osmosis water-making device is an important and precise component, and its operating state directly determines the performance of the water generator. This paper analyzes a vibration fault of a high-pressure pump and finds the maintenance points and precautions in its daily operation.

1. Introduction
The reverse osmosis method utilizes the semi-permeable property of the reverse osmosis membrane. When the seawater pressure entering the reverse osmosis element is higher than the osmotic pressure, the water permeates into the fresh water side through the semi-permeable membrane, and the salt film is retained on the concentrated water side, thereby dehydrating the brine. The device can be operated continuously under normal temperature and no phase change conditions. Only the high-pressure pump and the pre-treatment system of the sea water pump consume electric energy, and the single-stage demineralization rate can reach 99%. At present, the world's multinational naval vessels and ocean-going vessels with dense personnel have adopted reverse osmosis desalination devices.[1,2]

2. Failure phenomenon
In the first half of November 2017, during the voyage of the Pacific Ocean, the engine attendant found during the inspection: the pressure gauges of the pretreatment part of the 1# reverse osmosis unit were normal, the inlet pressure of the fine filter was 0.13 MPa, and the outlet pressure of the microfilter was 0.08 MPa. The pressure at the inlet of the high pressure pump (ie, the outlet of the microfilter) is not less than 0.02 MPa; however, the pump body of the high pressure pump and the high pressure hose are strongly vibrated. Less than a month after the interval, a similar failure occurred in the 2# reverse osmosis unit at the end of November, causing the equipment to stop.
Fig. 1. High pressure pump installation diagram.

The high-pressure pump is an App3.5 swash plate type plunger high-pressure pump, which belongs to the precision pump type. According to the maintenance requirements of the instruction manual: 8000 h maintenance-free; but the two reverse osmosis water generators after the transformation run less than 800 h failures in succession are an abnormal phenomenon. [3,6]

3. Water machine principle and performance characteristics

3.1. Water machine working principle and composition

The reverse osmosis water generator is mainly composed of a booster pump, a multi-media filter, a fine filter, a micro-filter, a high-pressure pump, a buffer, reverse osmosis membrane, a cleaning tank, an electric control box and an electric instrument, as shown in Fig. 2.

Fig. 2. Reverse osmosis water machine working principle.

The reverse osmosis water machine is divided into two parts: pretreatment and reverse osmosis. The purpose of the pretreatment section is to treat the seawater as water that meets the water ingress requirements of the reverse osmosis membrane. The pretreatment part adopts the type of “booster pump + multi-media filter + fine filter + micro-filtration” to ensure that the turbidity of the reverse osmosis membrane is <1 NTU. The booster pump section provides a source of pressurized water to the pretreatment section.

The reverse osmosis section is composed of a high pressure pump, a buffer, reverse osmosis membrane, reverse osmosis membrane vessel, washing system, and the like. The production of fresh water by reverse osmosis principle must be carried out under high pressure, the working pressure is 4.0–6.8 MPa, the pretreated seawater enters the reverse osmosis membrane through the high pressure pump, the fresh water is transmitted through the reverse osmosis membrane, and the concentrated seawater is discharged to the outboard. Fresh water is tested by a salt meter. If the standard is reached, fresh water can be supplied to the fresh water system. If it is not up to standard, it will enter the discharge line.
The high-pressure pump of the water generator is a three-piston reciprocating pump before the modification. The output pressure fluctuates greatly, and the buffer can absorb and smooth the fluctuation, so that the water inlet pressure of the reverse osmosis membrane reaches a relatively stable state. Due to the poor stability of the high-pressure pump of the water generator, the fault is frequent, and it is later modified into the APP3.5 high-pressure pump produced by Danfoss Company of the United States. The pump is a swashplate axial piston pump with stable performance.

3.2. Performance characteristics of APP3.5 high pressure pump[1]
(1) The suction pressure of the swashplate axial piston pump is not allowed to be too low. The allowable suction height is generally not more than 0.5 m, the inlet pressure should not be lower than 0.08 MPa, and some models are not allowed to self-prime.

(2) In order to fully lubricate the bearings and lubrication surfaces in the high pressure pump, the pump that is used for the first time or just repaired must be filled with oil before starting the pump.

(3) The high pressure pump should not be operated for a long time at zero displacement. Since the high pressure pump does not generate the discharge pressure at the time of zero displacement, the friction surfaces are not lubricated and cooled by the leakage oil, and the wear is easily increased, and the liquid in the high pressure pump casing is heated.

(4) The working fluid must be kept clean. If the liquid contains solid impurities, it will not only aggravate the wear and reduce the volumetric efficiency, but also may block the passage inside the pump (for example, the plugs in the plungers, the small through holes in the shoes will lose the static pressure balance and cause serious wear), or cause jamming, etc. malfunction.

(5) The precision of the matching parts in the pump is very high. Special care should be taken to keep it clean during disassembly and assembly. Before using the parts, apply volatile detergent to clean the parts and dry them with compressed air. It is not suitable to dry with cotton yarn.

4. Troubleshooting and analysis
For the fault situation, the turbine personnel separately disassembled and inspect the high pressure pumps of the two water generators. During the process of dismantling the high-pressure pump (see Figure 3), it was found that there were 2 plunger sliding shoe parts inside the high-pressure pump of the 1# water machine falling off, and there was a plunger sliding shoe part inside the high-pressure pump of the 2# water machine falling off. See Figure 4.

Fig. 3. Disassemble high pressure pump.

Since two reverse osmosis water generators both have high pressure pump failures, and there is only one spare part in the warehouse, after the turbine personnel agreed, the 1# reverse osmosis high pressure pump was completely replaced, and then two fault high pressure pumps were assembled into one. A good high-pressure pump (use a good plunger slide to replace the damaged part) is installed to the 2# reverse osmosis water machine.

Fig. 4. The plunger sliding shoe is abnormally separated
4.1. Troubleshooting

(1) Multi-media filter. When the multi-media filter is operated for a long period of time, a large amount of impurities accumulate inside, increasing the filtration resistance. Observe the pressure difference between the inlet and outlet of the multi-media filter, and backwash the multi-media filter when the inlet and outlet pressure difference is increased to 0.05 MPa. During the backwashing, the multi-media filter multi-way valve is rotated to the “backwashing” part, the device is automatically operated, and the backwashing time and backwashing process of the multi-media filter are controlled by the automatic multi-way valve.

(2) Fine filter and micro filter. When the fine filter and microfilter work for a long time, the filter element is clogged and the filter element needs to be replaced. Observe the fine filter and microfilter inlet and outlet pressure gauge. When the inlet and outlet pressure difference reaches 0.1 MPa or more, the filter element needs to be replaced. The fine filter is equipped with a filter whose filtration precision is 5 μm, and the micro filter is equipped with a filter whose filtration precision is 3 μm.

(3) Fresh water washing device. After the reverse osmosis water machine has been running for a period of time, it is necessary to use fresh water to flush the internal piping and membrane groups of the device, usually before the ship returns to the freshwater waters, and the flushing cycle is uncertain.

4.2. Failure mechanism analysis

(1) The outlet pressure of the booster pump can reach 0.3 MPa or more. When the seawater is sent to the multi-media filter, the outlet pressure is also above 0.2 MPa, minus 0.05 MPa at which pressure difference between the inlet and outlet of the multi-media filter the multi-media filter needs backwash. The operation, so the outlet pressure of the multi-media filter generally reaches 0.15 MPa, which meets the requirements of the pre-treated water entering the fine filter. The multi-media filter is equipped with two kinds of filter materials. The upper layer is quartz sand with a particle size of 0.5~1.0 mm, and the lower layer is quartz sand with a particle size of 1.0~2.0 mm. The multi-media filter materials have been used for 9 years, and if they cause pollution to water quality is uncertain.

(2) When the pressure difference between the inlet of the fine filter and the outlet of the micro filter reaches 0.1 MPa or more, the engine personnel replaces the filter element of the fine filter and micro filter. Therefore the high-pressure pump may run for a period of time at an inlet pressure of 0.05 to 0.10 MPa. Although the inlet required pressure of the high pressure pump is not lower than 0.02 MPa, this requirement is the requirement of the high pressure pump before the osmosis water machine is rebuilt. After the equipment is rebuilt, the turbine personnel still manage the equipment according to the requirements before the transformation, which may lead to the high pressure pump malfunction.

(3) According to the previous frequency of use, the cycle of washing the reverse osmosis water machine by the turbine personnel using fresh water rinsing device is 20~40 days. The long-term operation and non-flushing of the equipment cause the pipe, filter element and membrane group to be dirty. More impurities enter the high pressure pump, which may cause the high pressure pump to malfunction. [4]

5. Improvement measures and effects

5.1. Improvement measures

(1) Due to the complicated procedures and processes for replacing the filter materials inside the multi-media filter, it needs to be dismantled and returned to the factory for construction. The marine engineers agree to replace the filter materials when the ship is in medium maintenance for 10 years.

(2) Because the plunger slide shoe of high pressure pump can not appear pull force [5], the high pressure pump can only use the pressure of the pretreatment water to press the water into the plunger, so the high pressure pump has no self-priming capability, and the booster pump is needed to pressurize the seawater to the inlet of the high pressure pump. The inlet pressure of the high-pressure pump before the transformation is required to reach 0.02 MPa. This standard is still used after the transformation, but the high-pressure pump fails in succession. Therefore, the turbine personnel
increase the working pressure of the pretreatment water, and the new standard is required to be no less than 0.1 MPa.

(3) Set the frequency of the fresh water flushing device, and require the turbine personnel to stop the equipment after 20 days of continuous operation, and use fresh water to flush the device.

5.2. Effect test
Combined with the fault response measures, the turbine personnel started the reverse osmosis water machine, and all the parameters were normal. During the use process, the turbine personnel maintained the reverse osmosis water machine according to the new standards and requirements. At present, the two reverse osmosis water generators have been running continuously for 3,600 h, and the high pressure pump is in normal condition without similar failure.

6. Conclusion
The author describes the application status of marine reverse osmosis water machine, analyzes the advantages and disadvantages of reverse osmosis technology, introduces the working principle and component composition of a ship reverse osmosis water machine, and focuses on the performance characteristics and precautions of high pressure pump. In the case of failure, find the fault point by disassembling the high-pressure pump, summarize the maintenance measures in daily work, analyze the mechanism of the fault, preliminly locate the cause of the fault, formulate countermeasures, and verify the effect. The managements used in this paper can provide reference for the operation and management of this type of equipment for related ships.

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