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Investigations on the applicability of hydrostatic bearing technology in a rotary energy recovery device through CFD simulation and validating experiment

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HIGHLIGHTS

- The hydrostatic bearing was firstly introduced into the RERD
- The hydrostatic bearing favors for the establishment of fluid film lubrication in RERD
- The circular clearance regarded as fluid restrictor was optimized
- Experimental results are in accordance with CFD simulations

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ABSTRACT

Based on the structural characteristics of the rotary energy recovery device, the hydrostatic bearing was established on both sides of the rotor. Effects of the hydrostatic bearing on the resultant force and fluid film thickness were investigated by the methods of computational fluid dynamics simulation and validating experiments. Simulation results indicate that resultant force rises linearly with the increase of both operating pressure and thickness difference between the upper and lower fluid films, indicating that there exists a cooperative function between the upper and lower fluid films which favors for the self-adjustment of film thickness and resuming the rotor to a stable lubrication state when the pressure changes. The circular clearance regarded as fluid restrictor was optimized in order to adjust the fluid film thickness rapidly and the best circular clearance is about 0.03 mm. The experimental results indicate that the practical resistance of the rotor can well be reflected by the changing trend of the experimental rotor speed at operating pressure from 0.1 MPa to 6.0 MPa, and is in good accordance with the theoretical resistance calculated by using the simulation results, verifying that the simulation model was reliable. This study provides an applied structure for improving the frictional state of the rotor and prolonging the working life of the device.

1. Introduction

Seawater reverse osmosis (SWRO) technology is now a well established water desalination way to solve the water shortage problem globally [1–4]. The rotary energy recovery device (RERD) can effectively recover the pressure energy from the rejected high pressure brine on the principle of positive displacement and has become one of the key facilities to reduce the operational cost in SWRO system [5,6]. However, several challenging issues associated with two friction pairs between the rotor and the endcovers still exist, such as conflicts between the lubrication and the wear, and between the sealing and the leakage [7]. As has been known, a small clearance could bring a good seal performance by making the leakage passage much narrow. However, when the mating clearance is decreased to an extremely small level, the friction pair may work in the state of contact friction [8], which will raise the damage on the contact faces and thus lessen the lifetime of the device. Therefore, finding a proper way to keep the rotor working in the fluid film lubrication condition at a small clearance becomes the key target in the RERD field.

The hydrostatic bearing is an effective lubrication solution to eliminate any possibility of surface-to-surface contact. The structure of the hydrostatic bearing employs an external high pressure supply system to form the hydrostatic pressure and provide the load capacity in the bearing [9]. Numerous studies on the hydrostatic bearing within the

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Nomenclature

ρ	density of the fluid (kg/m^3)
ε	dissipation rate (m^2/s^3)
μ	molecular viscosity (Pa s)
μ_t	turbulent viscosity (Pa s)
c_1, c_2, c_μ, σ_k, σ_ε	constant
F_u	bearing load capacity of upper fluid film (N)
F_l	bearing load capacity of lower fluid film (N)
F_r	resultant force of fluid film (N)
k	turbulent kinetic energy (m^2/s^2)
p	static pressure (Pa)
u_i	time mean velocity (m/s)

axial-piston pumps were focused on the operating conditions and geometric parameters.

N.D. Manring [10] experimentally investigated the influence of different pocket geometries on the performance of slipper bearing within axial-piston pumps, and pointed out that the pocket geometry has a significant impact on the bearing performance. J.K. Kim [11] experimentally studied the fluid film between the valve plate and the cylinder block in the axial-piston pumps by using a gap sensor. The results indicated that the valve plate with a bearing pad shows better film thickness contours than that without a bearing pad. Z.L. Guo [12] firstly used computational fluid dynamics (CFD) to simulate the pressure field and calculate the static and dynamic characteristics of hydrodynamic bearings, hydrostatic bearings and squeeze film dampers for rotating machinery. S.L. Nie [13] proposed the hydrostatic slipper bearing with an annular orifice damper in water hydraulic axial piston motor. The experimental results indicate that the hydrostatic slipper bearing with an annular orifice damper would decrease the possibility of the severe wear between the slipper pad and the swash plate. J.H. Shin [14] investigated the effect of surface non-flatness on the lubrication characteristic of the valve part by observing the fluid film geometry and power loss in a swash-plate type axial piston machine.

Since there are some structure similarities between the axial piston pump and the RERD for the friction pair, the hydrostatic bearing can also be utilized on the RERD to form the fluid films between the rotor and the endcovers that slide against each other, and to reduce the friction force of the device. Different from the axial piston pump, the friction pairs should be established on both the upper surface and the bottom surface of the RERD rotor. So the study results concerning the friction pair of the axial piston pump cannot be used on RERD directly.

In this paper, to establish a fluid film lubrication environment for the rotation of the rotor, a hydrostatic bearing structure was firstly introduced and incorporated in the RERD. Through CFD simulation, the fluid film lubrication state of the rotor was judged by analyzing the resultant force of the rotor at different fluid film thickness and operating pressure. Besides, the dimension of circular clearance was optimized by the reasonable simulation model. In addition, to verify the simulation model, the rotor speed of the self-driven RERD was experimentally tested at different operating pressures.

2. Description of the hydrostatic bearing on the RERD

2.1. Work principle of the RERD

The schematic representation of the SWRO coupled with the RERD is provided in Fig. 1. According to the diagram, the seawater delivered by the seawater pump is divided into two streams, one stream to the RERD and the other to the high pressure pump. The stream to the RERD is firstly pressurized by the high pressure brine from the membrane modules. Then the pressure of this part stream is increased by the boost pump to meet the desired operating pressure of the system. As a result, the stream pressurized by the RERD and the boost pump converges with the stream pressurized by the high pressure pump as a whole feed to the RO modules.

As seen in Fig. 1, the core components of the RERD consist of the seawater endcover, the rotor, the rotor sleeve and the brine endcover. The seawater endcover contains a port for incoming low pressure seawater (LP-IN), and a port for outgoing high pressure seawater (HP-OUT). The brine endcover likewise embodies two ports (HP-IN and LP-OUT) [15]. The rotor containing axial ducts arranged in a circle is fit into a rotor sleeve between the seawater endcover and the brine endcover. The rotor is the only rotating part of the device [16].

The RERD transfers the hydraulic energy by putting the streams in a direct, momentary contact in the rotor ducts [6,17]. At any time, half of the rotor ducts are exposed to low pressure (LP) stream and the other ducts to the high pressure (HP) stream [18]. The LP stream and the HP stream are separated by a sealing area in the endcovers.

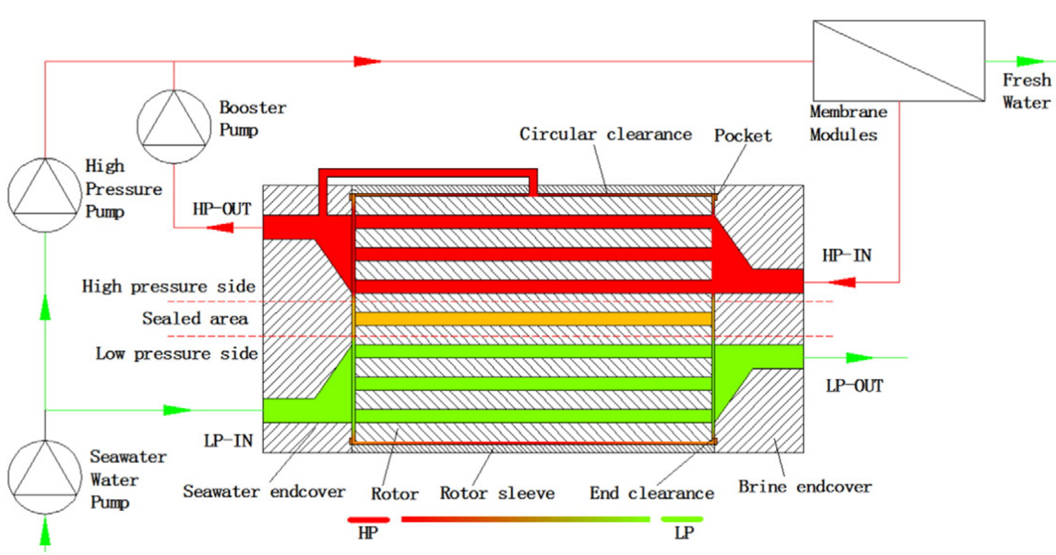

Fig. 1. Schematic representation of the SWRO and the RERD.