Frictional Properties of Rotary Glyd-ring under Water Lubrication

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Abstract. The ocean, which covers about 70% of the earth surface, contains abundant natural resources, such as organisms, minerals, energy resources, and etc. Development and utilization of ocean resources is an important way to solve the problems of population, resources and environment that human beings are confronting with. Besides, the underwater operation equipment plays an important role in the development and utilization of the ocean. The rotary dynamic seal, which exerts great effects on the static and dynamic performances, reliability, life span and etc. is a key technology of the underwater rotating equipment. This research focuses on the frictional properties of rotary dynamic Glyd-ring under water lubrication. A physical model is proposed to study the effects of rotational speed and working pressure on the maximum Von Mises stress numerically. A rotary seal test bench is developed and experiments have been carried out to investigate the friction, torque of Glyd-ring under different rotational speed, different sealing pressures on one or both seal sides. The research results provide a basis for the design of dynamic seals for deep sea equipment.

1. Introduction

In order to improve the sealing performance, domestic and foreign scholars have carried out a series of research on dynamic sealing performance. For example, Robert Bosch GmbH of Germany[1-3] used the finite element analysis software ABAQUS to establish a model to verify the accuracy of the lubrication theory of the ring sealing surface. Aachen University of Technology uses the test bench for four different sealing rings[4] (Stern seal, Glyd-ring, PU compound seal ring, Combined sealing ring) in different working conditions (different pressure (25bar~100bar), different oil temperature (30°C~70°C), different motor frequency (2.8Hz~12.5Hz), different speed (0~10m/s); and the dynamic sealing performance under the test has been studied. It is concluded that the combined sealing and PU compound seals composed of PTFE and O-ring seals have the advantages of good lubricity, and are more suitable for dynamic sealing; University of Alabama Huntsville[5] used the analysis software ABAQUS to establish a simulation model of the O-ring seal, and analyzed the change of the seal ring load of the O-ring at different compression ratios. Tests show that as the compression ratio increases, the load rate of the O-ring gradually decreases; Tsinghua University[6-7] uses the analysis software to establish the axisymmetric model of the nitrile rubber O-ring, the static seal of the nitrile rubber O-ring and the micro-motion sealing performance was simulated and experimentally studied. In addition, universities such as North University of China[8], Beijing University[9] of Aeronautics and Astronautics, and Jiangsu University[10] have also conducted research on the dynamic sealing performance of seal rings.
2. Modelling and Simulation

2.1. Grid model
The physical model of the rotary dynamic seal is established. The specific specification of the Glyd ring is RC11-Q-8×12.9×2.2, and the overall structure has axis symmetry. It is assumed that the piston rod and the sleeve will not be deformed and is defined as an analytical rigid body. The sealing structure is expanded to convert the rotational motion into a linear motion. For the convenience of calculation, the expanded 1/10 model is built and the mesh is divided. Figure 1 shows a simplified mesh model of a rotating dynamic seal. During the conversion process, the speed conversion formula is:

\[ v = \pi dn \]  

(1)

Where:  
\( v \) is the tangential velocity;  
\( n \) is the motor speed;  
\( d \) is the inner diameter of the Glyd-ring.

![Figure 1. Rotating dynamic sealing mesh model.](image)

2.2. Material model
The O-ring of the Glyd Ring is a nitrile rubber material, which is an incompressible superelastic body[11]. It is described by a two-parameter Mooney-Rivlin model[12]. The Mooney constant is \( C_{10}=1.87 \), \( C_{01}=0.47 \). The material of the square ring is PTFE, the material of the sleeve is aluminum bronze QAL9-4, the material of the piston rod is stainless steel 316L, the friction coefficient of O-ring is 0.3, the friction coefficient of square ring is 0.05, the specific parameters are as follows in Table 1.

| Parameter       | Elastic Modulus E(MPa) | Poisson ratio | Superelastic parameter |
|-----------------|------------------------|---------------|------------------------|
| Piston rod      | 2.11×10^5              | 0.3           | -                      |
| Sleeve          | 1.1×10^5               | 0.33          | -                      |
| Square circle   | 960                    | 0.45          | -                      |
| O-ring          | 6.1                    | 0.499         | \( C_{10}=1.87 \) \( C_{01}=0.47 \) |

2.3. Boundary Condition
In the process of simulation, there are more boundary conditions, considering the actual situation and the feasibility of the simulation, within the error tolerance, a series of assumptions are made.

- The material stiffness of the piston rod and the sleeve is much higher than the stiffness of the Glyd ring, so the deformation can be neglected and defined as the analytical rigid body.
• Ignore the temperature change and wear caused by the friction during the process of simulation analysis.
• The Glyd ring is considered to be caused by a certain displacement of the boundary of the constrained piston rod.

2.4. Analysis Step
According to the model, the sleeve is fixed during the whole analysis process, and the sleeve is completely fixed when the boundary condition is set. The analysis of the rotary dynamic sealing characteristics of the Glyd ring is divided into three analysis steps:
• Applying a certain amount of pre-compression to the Glyd ring, that is, setting the displacement of the piston rod in the Y-axis direction;
• Applying a certain working pressure to both sides of the Glyd Ring;
• Apply a certain speed to the piston rod (Rotary axis).

3. Test Model

3.1. Test Plan and Data Handle
First, the air in the two water chambers is taken out, and the water is filled into the two water chambers; the AC servo motor is started. After the motor speed is stabilized, the sliding table on the rodless cylinder starts to operate, and each sensor works normally, the dynamic sealing characteristic test bench data The display in the acquisition system is normal, and the test runs for several cycles. The mounting position of the sleeve assembly Glyd ring is A, B, C, as shown in Figure 2.

3.1.1. Apply different pressure to one side of the Glyd ring
Firstly, the unilateral compression of the Glyd ring is tested. The Glyd ring is not set at the B point, the cavity 1 and the cavity 2 are connected, and the rotation speed is set to a certain value, in the step of 2 MPa, in the circle. The pressure of water in the two chambers was recorded. When the pressure was 0 to 10 MPa, the tensile sensor data is recorded as \( F_1 \), and the data \( F_1 \) obtained at this time. It is the friction force of the two Grad rings, so the friction force of the Glyd ring on one side under pressure is \( F_{a1} = \frac{F_1}{2} \).

The values of \( P_b \) and \( F_{a1} \) were obtained through experiments, and the graph of a was drawn to analyze the relationship. The contact pressure distribution of the sealing ring of the Glyd ring is obtained. The curve of contact pressure with water pressure is obtained, and a graph is drawn to analyze the relationship.

3.1.2. Apply the same pressure to both sides of the Glyd ring
Install the Glyd ring at all of A, B, and C. The cavity 1 and the cavity 2 are not connected. The pressure \( P_b \) (0~10MPa) of the cavity 1 and the cavity 2 is adjusted to be the same, and the rotation speed is set to a certain value. And record the
current pressure sensor $F_2$, and compare the situation of a, we can get the friction force $F_b = F_2 - F_1$ of the current ring.

The $P_b$ and $F_b$ values were obtained through experiments, and a graph was drawn. The conclusion was obtained by comparing a.

3.1.3. Apply different pressure to the sides of the Glyd ring. Install the Glyd ring at all of A, B and C. The two chambers are not connected. Adjust the pressure of the water in the chamber to a certain value, set the rotation speed to a certain value, and record the pressure $P_c$ of the chamber 2 as 0 to 10MPa, the pressure sensor shows the number $F_3$. When the pressure of the two chambers is the same as the pressure of the chamber 1 at the same time, the pressure sensor shows $F_4$. Compared with the case a, the gray circle can be obtained. Friction force $F_c = F_3 - F_1 - F_4/2$.

The $P_c$ and $F_c$ values were obtained through experiments, and a graph was drawn. Comparing the case a, and the conclusion was drawn.

3.2. Experiments
The rotary seal test bench is shown in Figure 3. The overall physical map of the test bench is shown in Figure 4.

![Figure 3. The structure of the test bench](image)
1-AC servo motor 2-motor connection board. 3,5-flat key. 4, 7-coupling. 6-torque speed sensor. 8-axis.
9, 10, 11-screw assembly 12,13,14-screw assembly. 15-body bracket 16-test section.

![Figure 4. The photo of the rotary dynamic sealing Characteristic test bench](image)
The AC servo motor 1 drives the shaft 8 to rotate continuously through the couplings 3, 7. The motor speed is controlled by the driver, the pressure regulating device is responsible for adjusting the pressure of two water chambers, and the pressure sensor is responsible for recording the pressure of the water chambers, the torque-speed sensor 6 is responsible for recording the rotational speed and the friction torque of the sealing ring. Finally, through the data acquisition system of test bench, the data of rotating speed, pressure and friction torque will be stored and processed.

4. Result Analysis

4.1. Effect of Speed on Contact Pressure
The moving speed of the piston rod is set to 0.2m/s, and the working pressures of 0MPa, 2MPa, 4MPa, 6MPa, 8MPa and 10MPa are applied on one side of the Glyd ring, and the analytical working pressure
is obtained for the Glyd ring at different compression ratios. The experimental results of the influence curve of Mises stress show that the larger the compression ratio after applying the pressure load, the smaller the maximum Mises stress of the Glyd ring. When the compression ratio $\omega$ is 17%, the Mises stress changes more smoothly with the increase of the pressure, so the pre-compression rate $\omega$ analyzed in the experiment of performing the rotary dynamic sealing is selected to be 17%.

![Figure 5. contact pressure distribution of sealing surface at different rotational speeds](image)

When the pre-compression amount is 17%, the working pressure of 2 MPa is applied on both sides of the Glyd ring respectively, and the distribution of contact pressure of the sealing surface of the Glyd ring is obtained by simulation at 500 rpm, 1000 rpm, 1500 rpm, 2000 rpm, and the test results are shown in Figure 5. It can be concluded that the maximum contact pressure of the sealing surface of the glyph ring is basically stable at about 3.6 MPa, which is less affected by the rotational speed.

### 4.2. The effect of Working Pressure on Contact Pressure

According to the results of the modeling, get the Bode simulation in the ABAQUS/CAE. The simulation of the modeling as follows.

![Figure 6. Contact pressure distribution of the sealing surface on one side of the pressure](image)
The simulation results show the maximum contact pressure of the sealing surface as a function of the working pressure, as shown in Figure 8.

It can be seen from the above figure that under the three kinds of compression conditions, the maximum contact pressure of the sealing surface of the Glyd ring is greater than the current water pressure. The maximum contact pressure gradually increases with the increase of water pressure, and the maximum contact pressure of the sealing ring on both sides is less than the maximum contact pressure when one side is pressed.

4.3. The Effect of Constant Pressure Shift on Friction Torque

When the pressure of the water on both sides of the Glyd ring is 0 MPa, the friction torque curve of the Glyd ring at different rotational speeds is obtained.

It is concluded that when the two sides of the Glyd ring are not under pressure, the frictional moment of the Glyd ring is less affected by the rotational speed, fluctuating around 0.042 N•m, and the variation is small, and the contact with the simulation is obtained. The pressure is consistent with the lesser effect of the speed.

4.4. The Effect of Constant Speed Variable Pressure on Friction Torque

When the rotation speed n=200 rpm, the pressure method corresponding to the simulation was tested, and the curve of the Glyd ring under three kinds of pressures was obtained, as shown in Figure 9.

It can be seen from Figure 10 that the friction torque of the Glyd ring increases with the increase of the working pressure when the rotation speed is constant, and the friction torque when the two sides are pressed is smaller than the friction torque when the pressure is pressed on one side; The friction torque at the same pressure on both sides is smaller than the friction torque at different pressures on both sides. The test results are in agreement with the simulation results.
Figure 9. Relationship between maximum contact pressure friction and pressure on the sealing surface of the Glyd ring

Figure 10. The relationship between torque and pressure

5. Conclusion
In this paper, the Glyd Ring is taken as the research object, and the test bench for rotating dynamic sealing characteristics is developed. The simulation and experimental research on the dynamic sealing characteristics under water lubrication conditions are carried out, and the following conclusions are obtained:

The maximum Mises stress and the maximum contact pressure on both sides of the Glyd-ring are smaller than those on the single side;

Under constant working pressure, the rotational speed exerts little effects on the frictional torque;

Under constant rotational speed, the frictional torque of the Glyd-ring gradually increases with the increase of the working pressure, the maximum Mises stress and friction torque of the Glyd-ring under both sides with pressures are smaller than one side with pressures.

6. Acknowledgments
This work was supported by the National Natural Science Foundation of China (51275495, 51475197); the Key Research and Development Plan of Shandong Province of China (2017GGX30106); the Natural Science Foundation of Shandong Province of China (ZR2018MEM023); the Fundamental Research Funds for the Central Universities (201562009); the Science and Technology on Underwater Vehicle Technology Research Fund (SXJQR2017KFJ04); Self-sustaining Intelligent Argo Buoy of 4000 Meters Deep Sea(ZR2016WH02), the Goal-oriented Application Fundamental Research of the Natural Science Foundation of Shandong Province of China ("10,000-meter Deep Sea Action Plan"), 2016/08-2018/12.
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