Flow field distribution of liquid film of water lubricated bearing-rotor coupling systems

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Abstract. According to the desalination high-pressure pump water lubricated bearing-rotor coupling systems flow field distribution of liquid film in the starting transient process and its power transmission mechanism can lay the foundation of further exploring and judging lubrication state at the boot process. By using the computational fluid dynamics Fluent secondary development platform and calling the relevant DEFINE macro function to achieve the translation and rotation movement of the journal, we will use the dynamic grid technique to realize the automatic calculation and grid update of water lubricated bearings 3d unsteady liquid film flow field, and finally we will dispose the results of numerical simulation and get the pressure. When the eccentricity is large, film thickness was negatively correlated with the pressure, and positive with the velocity. Differential pressure was negatively correlated with velocity. When the eccentricity is small, film thickness is no significant relationship with differential pressure and velocity. Differential pressure has little difference with velocity. When the eccentricity is large, film thickness was negatively correlated with the pressure, and positive with the velocity. Differential pressure was negatively correlated with velocity. When the eccentricity is small, film thickness is no significant relationship with differential pressure and velocity. Differential pressure has little difference with velocity.

1. Introduction
Reverse osmosis technology is a desalination technology which is high-efficiency and easy to use on a large scale. It is in broad application prospects especially in a time of scarce water resources [1]. High-pressure pump is the key equipment of reverse osmosis desalination [2], its typical structure is a new type of axial suction multistage sectional pumps, with the supporting of a rotor bearing. In the high-pressure multi-stage pumps, water-lubricated bearings at both ends of the rotor system simplify the structure of the pumps, which also improve the efficiency and service life [3-6]. Water lubricated bearing is the main elastic support components, whose performance will directly affect the formation of dynamic pressure liquid film, lubrication and the stability of the entire rotor system in the startup process. Due to the low viscosity of water (1/100 ~ 1/20 of oil viscosity), and the low film bearing capacity, the formation of hydrodynamic lubrication is difficult. As well as the pump unit startup, stop and the unit running speed changes, the water lubricated bearings is easy in boundary lubrication or dry friction state. It leads to some extreme phenomena such as unpredictable instability and growth of vortex, which will seriously affect the dynamic stability of the pump bearing-rotor system [7]. In some desalination systems [8-12], the high-pressure pump startup and stop frequently. Meanwhile, because
the rotor speed, film strength and the moment of the bearing - rotor system suffered a transient state in every startup process. Which results water lubricated bearing journal position in a transient state. In the startup state, the above various transient factors will directly affect the dynamic distribution of water lubricated bearing liquid film flow field, which further cause water lubrication complicated. The power transmission between water-lubricated bearings and rotor system is not only related to the distribution of film flow field and lubrication, but also closely related to dynamics of rotor system. Eventually a dynamic coupling system is formed [13].

It is CFD was used in this paper. With using FLUENT secondary development platform for programming journal of the shaft of the translational and rotational motion, combined with real-time updates of dynamic mesh grid. Finally FLUENT post-processing techniques were applied to deal with the startup transient numerical result. Then the transient distribution of three-dimensional film (velocity field, pressure field, etc.) of water-lubricated bearings flow field was obtained. It concluded the dynamic distribution of the film flow field of water lubricated bearing of high-pressure desalination pump in start transients.

2. Geometric modeling and meshing of three-dimensional film flow field [14]
This study will apply a type of high-pressure pumps as a sample to establish a physical model of FEM for water desalination lubricated bearings - rotor coupling system, which consists of six-stage impellers, balance wheel, balance disc and the front sliding bearings (B1), the back sliding bearing (B2), the shaft. The back balance wheel is applied as the slide shaft and rotor. The physical assembly model of the coupling system was shown in Figure 1.

![Figure 1. The desalination high-pressure pump’s water lubricated bearing-rotor coupling systems](image)

This paper will apply the water lubricated bearing B1 as a sample, of which the main parameters is: bearing width B is 60 mm, bearing diameter D is 90 mm, journal diameter D is 89.7 mm, the radius clearance c is 0.15 mm, the rotate speed is 2980 r/min.

The geometrical modeling will use Geometry of ANSYS ICEM, which establishes a 3D flow field. As shown in Figure 2(a). Compared with the circumferential and axial dimensions, the film thickness is too small. Blocking of ANSYS ICEM is chosen. As shown in Figure 2(b).
3. UDF control of rigid body motion

The rigid body motion included the translation and the variable speed rotation. This paper will write the UDF through two DEFINE macro provided by the FLUENT Inc.

3.1 Using DEFINE\_ CG\_ MOTION macro to realize translation at journal

DEFINE\_ CG\_ MOTION macro, which mainly used for rigid body motion, is one of the ways to realize the control of dynamic boundary motion. It uses the above theoretical calculation data of discrete axis trace during writing the UDF, and the interval between each discrete point is 0.05s, the total time is 7.85s. Parameters are set individually in each time step to advance the movement of journal gradually. It can be determined as follows: ‘omega’ is set as 0; ‘dtime’ is set as 0.05s; the total time is 7.85s; ‘vel’ in the z axis is set as 0, namely $vel[2] = 0$, velocity component in the direction of x and y $vel[0]$ and $vel[1]$ can be determined by the ratio of interpolation and the time step of discrete axis trace coordinate $(x, y)$, it assumed that the velocity component in x and y direction is near to a constant in each micro time step. The UDF will conduct translational motion of journal along the known axis after the above the specific set of parameters in each time step.

3.2 Using the DEFINE\_ PROFILE macro to realize the variable speed rotation at journal

DEFINE\_ PROFILE macros can define boundary conditions and variables, such as velocity, pressure, temperature. In this study, the main idea is to make the speed of each unit center of the surface on the border of cylinder along their tangent direction of the circumference and contra-rotating, setting different rotating angular velocity within each time step iteration to implement change angular motion in the startup transient phase. Motion moving boundary journal schematic diagram was shown in Figure 3.

![Figure 3. Journal moving boundary motion schematic](image)

It assumes that the coordinates of journal on the moving boundary is center, centrey, center coordinates of either mess plane on moving boundary are $x, y$, either mess center and the journal on moving boundary center is angle, $r$, $w$, time, $v_x, v_y$. x velocity of tangential linear velocities of rotation in moving boundary are written by DEFINE\_ PROFILE macros, so as y velocity components. Water, of which viscosity is small, is the working media of water lubricated bearings. There are 3D incompressible turbulence characteristics in water lubricated bearing clearance flow. In this situation,
SST turbulence model, which takes the transmission of turbulent shear stress into account, will be chosen. Defined inlet pressure as 0.6 MPa (absolute pressure), outlet pressure as 0.1 MPa and the outer wall as the stationary wall. Besides, inner wall is defined as the velocity boundary condition, compiled UDF, with x, y velocity component of tangential linear velocities of rotation in moving boundary, is selected in the drop-down list. The UDF calculation program chart of x and y velocity component is shown in Figure 4.

![UDF Calculation Program Chart](image)

**Figure 4.** x and y velocity component of tangential linear velocities of rotation in moving boundary

Eventually, compiled UDF, with x, y velocity component of tangential linear velocities of rotation in moving boundary, will be loaded in the FLUENT. In addition, internal face should be set as boundary condition, two compiled UDF as x, y velocity, then transient change of angular velocity movement can be realized.

4. **Results and discussion**

After automatically calculating, a series of 0.05s intervals samples and data can be gotten, then import these into FLUENT for post processing to get the rules of hydrostatic pressure, absolute pressure and velocity distributions in whole startup transient transition process.

4.1 *The rules of static pressure distributions in startup transient transition process.*

After post-processing, the static pressure distribution of the three-dimensional film flow field of water lubricated bearings in each time of the startup can be gotten. Parts major changes characteristics, which reflect static pressure distribution of the three-dimensional film flow field in the startup, will be listed. Figure 5. shows the rules.
The static pressure distribution rules of three-dimensional flow field in startup phase are summarized below.

4.1.1 The static pressure of the inlet and the outlet. In startup, the static pressure of water lubricated bearing film both in the inlet and the outlet, are slightly lower than stop, and the static pressure were fluctuations during stop.

4.1.2 Variation of axial static pressure distribution. From the axial view, static pressure is gradually decreasing from import to export. When the eccentricity is large, which range from 0 to 1.5s, the minimum thickness of the film at the inlet and outlet differential pressure reaches a maximum value. With the increasing of film thickness on both sides, the differences between inlet and outlet pressure are gradually smaller; when the eccentricity is small, the differences will be significantly reduced.

4.1.3 Variation of circumference static pressure distribution. When the eccentricity is large, In the front of the inner wall, static pressure circumferentially distributed roughly parabolic, and reached its maximum in the minimum thickness, which increases with the film thickness on both sides of the static pressure decreases; In the end part of the inner wall, the static pressure remains constant. When the eccentricity is small, the static pressure nearly remains the same.

4.2 The rules of absolute pressure distributions in startup transient transition process. Because the inlet and the outlet pressure boundary conditions are absolute pressure, variation of absolute pressure distribution is the same as static pressure.

4.3 The rules of velocity distributions in whole startup transient transition process.
4.3.1 Radial velocity distribution of the inlet and the outlet. To illustrate the main features of the radial velocity distribution changes, the radial velocity distribution in 0.4s and 2s is being taken. As shown in Figure 6.

(a) 0.4s
(b) 2s

Figure 6. The main features of the radial velocity distribution in startup phase

4.3.1.1 Radial velocity distribution of inlet

As shown in Figure 6(a), the speed radial from the inner wall to the outer wall increases first and then decreasing, the increasing rate is less than the decreasing rate. Due to the viscosity of water is small, the impact of the rotation around its journal circumferential velocity of the fluid is small, so the velocity distribution above may be differential pressure between the inlet and the outlet causing a greater axial flow, which is somewhat similar to the two-dimensional parabolic Poiseuille flow distribution [15] speed.
4.3.1.2 Radial velocity distribution of the outlet
In the beginning of the startup, the radial velocity distribution of the outlet is similar to the inlet, but the speed is smaller than the inlet. Then, the outer wall will appear high-speed area alternately, as shown in Figure 6(b).
To summarize the variation of axial and circumferential velocity distribution, the main distribution will be shown in Figure 7.

4.3.2 The rules of circumferential velocity distribution
When the eccentricity is large: The velocity distribution of circumferential velocity is substantially "concave" parabolic, and reached a minimum at the minimum thickness of the film. However, if not, it presents as a wave with little amplitude.

5. Conclusion
3D dynamic distribution of the film flow field of water lubricated bearing of high-pressure desalination pump in start transients is as follows:
1) When the eccentricity is large, film thickness was negatively correlated with the pressure, and positive with the velocity. Differential pressure was negatively correlated with velocity. When the eccentricity is small, film thickness is no significant relationship with differential pressure and velocity. Differential pressure has little difference with velocity.
2) It will dispose the results of numerical simulation and get the pressure and velocity distribution of 3d unsteady liquid film flow field in the startup phase, it provides certain numerical reference for revealing the development of water lubrication status and power transmission mechanism in the boot process.

6. Reference
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