## ARTICLE

# Transient Simulation on Dynamic Response of Liquid Annular Seals

**Li Song[1]   Pingwei Chen[2,3*]   Tong Wang[3]   Wensheng Ma[2]**

1. China Nuclear Power Engineering Co.Ltd., Shenzhen, Guangdong, 518124, China
2. National Enterprise Technology Center of CQPI, Chongqing, 400033, China
3. School of Mechanical and Powder Engineering, Harbin University of Science and Technology, Harbin, 150080, China

| ARTICLE INFO | ABSTRACT |
|---|---|

Transient change of the operating parameters has a serious influence on the stability of liquid annular seals. Take the liquid annular seals as a research object, a numerical method based on six-degree-of-freedom (6DOF) to analyze the dynamic response of liquid annular seals under gravity impact load. The variations of the force of liquid seal and pressure as well as the axis trajectory in time history are investigated. The influence of different sealing clearance, different liquid viscosity and different rotor speed is also studied. The results show that the maximum sealing pressure and sealing force of gravity direction will increase greatly in a very short time and then reduce rapidly. When sealing clearance increases, the displacement response amplitudes of axis trajectory, the maximum sealing force of gravity direction and maximum sealing pressure also increase. When liquid viscosity increases, the displacement response amplitudes of axis trajectory, the maximum sealing force of gravity direction and maximum sealing pressure decrease. We also found that different rotor speed has almost no influence on the maximum sealing force of gravity direction and maximum sealing pressure.

## 1. Introduction

As an important part of the multi-stage Centrifugal pump, hydraulic turbine and other rotating power machinery, the annular seal plays an important role in restraining the internal leakage of the machinery and balancing the axial force, common Structure of the annular seal is generally located in the impeller annular seal, inter-stage seal. A lot of research has been done in the area of the annular seal as well as the Rotor Dynamics [1-4]. In the process of starting and stopping of the rotor, the rotor and seal will bear a great impact force. A lot of scientific research has also been carried out on the characteristics of fluids under transient impact force, for example, Ma Jinkui studied the variation of the minimum oil film thickness, the maximum oil film pressure and the Axis trajectory of the rotor under different pulse [5], Rao calculated the axial trajectory of the rotor under critical speed and unstable speed, and calculated the dynamic analysis of the rotor-bearing under shock excitation [6], TICHY analyzed the influence of the transverse impact load and the impact load time on the axial trajectory of the rotor [7], Li Zhen et al. investigated the resonance of a rotor-bearing system under different kinds of loads [8], Yan et al. [9] studied flow field analysis using the CFX software,and the fluid-solid coupling analysis of the

annular seal structure and the Jeffcott Rotor. was done.

In this paper, the dynamic response of the annular seal is studied The sealing force, axial trajectory and fluid pressure under different sealing clearance, fluid viscosity and rotating speed were analyzed and compared.

## 2. Computational Model

The sealing structure of the annular seal is shown in Figure 1, and the calculation model is shown in Figure 2.
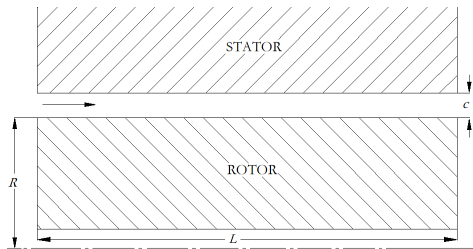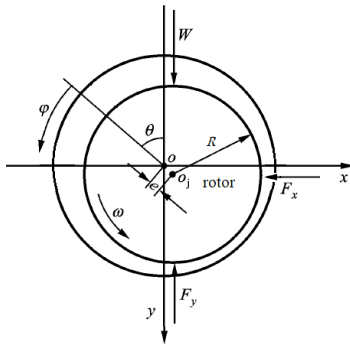


**Figure 1.** The annular seal structure



**Figure 2.** The calculation model

The dynamic equation of the seal is:

$$M\ddot{x} = F_x + Q_x$$
$$M\ddot{y} = F_y + Q_y + Mg$$

$\ddot{x}$ is the horizontal acceleration at the center of the rotor, $\ddot{y}$ is the vertical acceleration at the center of the rotor；

$F_x$ is the sealing force in horizontal Direction, $F_y$ is the sealing force in vertical Direction. $Q_x$ is the Impact load in horizontal Direction, $Q_y$ is the Impact load in vertical Direction； $M$ is the mass of rotor； $g$ is gravitational acceleration.To solve the above dynamic equations, step-by-step integration method is needed to obtain the position of the axis.position.

$$x(\tau + \Delta\tau) = x(\tau) + \dot{x}(\tau)\Delta\tau$$
$$y(\tau + \Delta\tau) = y(\tau) + \dot{y}(\tau)\Delta\tau$$

$$\dot{x}(\tau + \Delta\tau) = \dot{x}(\tau) + \ddot{x}(\tau + \Delta\tau)\Delta\tau$$
$$\dot{y}(\tau + \Delta\tau) = \dot{y}(\tau) + \ddot{y}(\tau + \Delta\tau)\Delta\tau$$

$\Delta\tau$ is time step, $\tau$ is total time, The new sealing thickness can be obtained by using the new axial position. The iteration cycle is repeated until the total solution time is over.

## 3. Calculation Result

In the finite element model,the sealing radius gap c=0.25mm, the Sealing length L=50mm, Rotor radius R=50mm, The fluid is water, and the Viscosity is 0.001Pa.s, density is 1000kg/m³,the pressure change due to the transient impact load is not significant, the change of density is $10^{-5}$ order of magnitude, so is not considered in this article. The equivalent rotor mass is 25kg,the rotor speed is 3000r/min, in Fluent [10] software,The finite element model of the annular seal is shown in Figure 3, The grid of thickness is shown in Figure 4, Hexahedron element is used in the model, and the number of Mesh is about 1.8 million, It is verified that the further refinement of the grid has little effect on the calculation results. $k-\varepsilon$ turbulence Model is used, The inlet and outlet boundary is the pressure inlet and outlet condition, The inlet pressure is 0.2Mpa, the outlet pressure 0.1Mpa, The Wall surfaces are all set to adiabatic boundaries, The fluid and the wall adopt the smooth non-slip boundary condition.
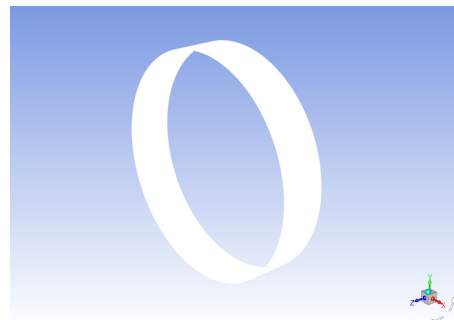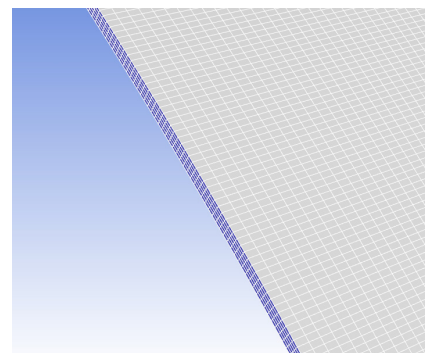


**Figure 3.** The finite element model



**Figure 4.** Local Grid

## 3.1 Dynamic Response under Different Radius Clearance

The axial trajectory, seal force in horizontal direction and gravity direction and seal pressure changing with impact time were calculated under the conditions of radius clearance 0.15 mm, 0.25 mm and 0.35 mm, respectively. see Figure 5-8 below. It is found that with the increase of the radius clearance, the amplitude of axial trajectory displacement response increases, the maximum value of sealing force in horizontal and gravity direction also increase, and the longer the time is needed. At the same time, with the increase of sealing radius clearance, the transient value of the maximum sealing pressure is also increase.
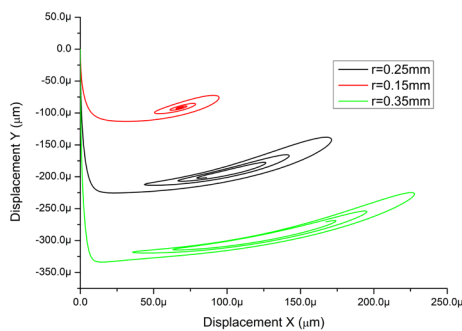


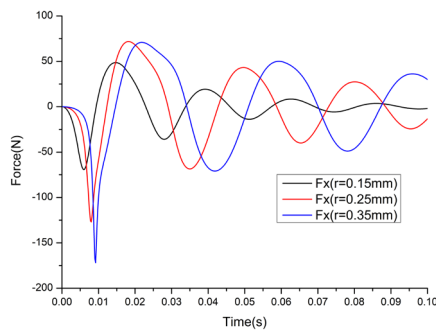**Figure 5.** Axial trajectory under different radius clearance



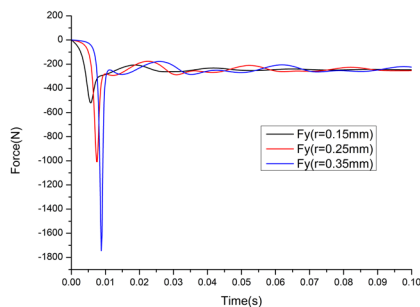**Figure 6.** The horizontal sealing force changes with time under different radius clearance



**Figure 7.** The sealing force of gravity direction changes with time under different radius clearance
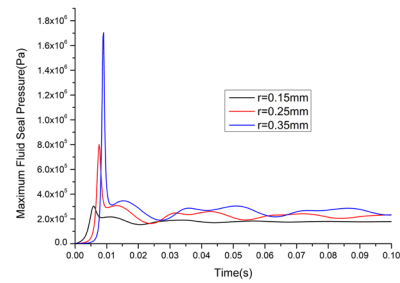


**Figure 8.** The maximum sealing pressure changes with time under different radius clearance

## 3.2 Dynamic Response under Different Fluid Viscosity

The axial trajectory, seal force in horizontal direction and gravity direction and seal pressure changing with impact time were calculated under the conditions of fluid viscosity 0.001Pa.s, 0.01Pa.s and 0.06Pa.s, respectively.see Figure 9-12 below. It is found that with the increase of the fluid viscosity, the amplitude of axial trajectory displacement response decreases, the maximum value of sealing force in horizontal and gravity direction also decrease, and the less time is needed. At the same time, with the increase of sealing radius clearance, the transient value of the maximum sealing pressure is also decrease.
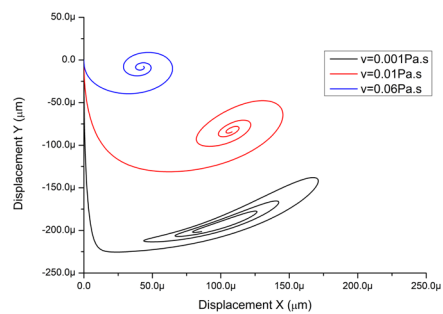


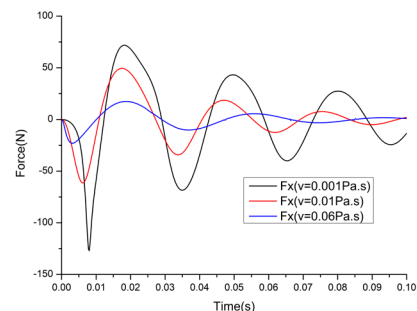**Figure 9.** Axial trajectory under different fluid viscosity



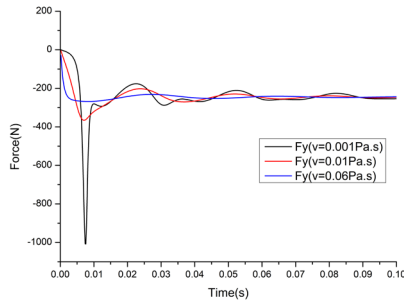**Figure 10.** The horizontal sealing force changes with time under different fluid viscosity

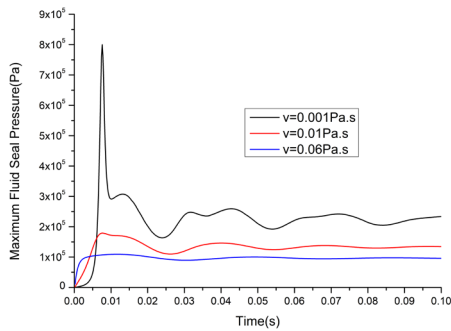**Figure 11.** The sealing force of gravity direction changes with time under different fluid viscosity



**Figure 12.** The maximum sealing pressure changes with time under different fluid viscosity

## 3.3 Dynamic Response under Different Rotational Speed

The axial trajectory, seal force in horizontal direction and gravity direction and seal pressure changing with impact time were calculated under the conditions of rotational speed 1000r/min, 3000r/min, 5000r/min, respectively.see Figure 13-16 below.It is found that with the increase of the rotational speed, the amplitude of axial trajectory displacement response decreases. The maximum value of the sealing force in the gravity direction is basically the same and the time is the same. At the same time, with the increase of the rotational speed, the transient value of the maximum sealing pressure is also the same and the time is the same.It shows that this phenomenon has little to do with the rotational speed.
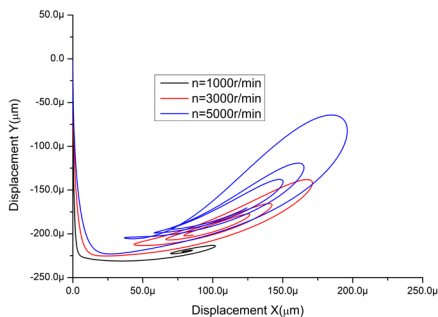


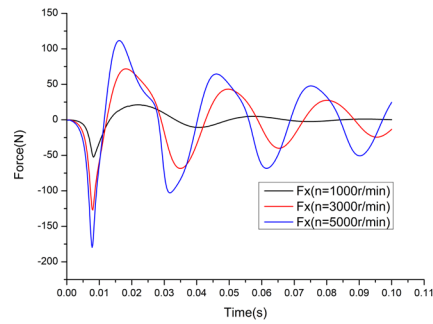**Figure 13.** Axial trajectory under different rotational speed



**Figure 14.** The horizontal sealing force changes with time under different rotational speed
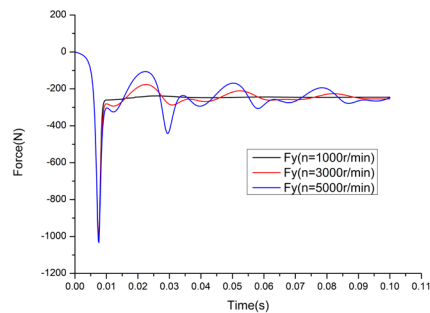


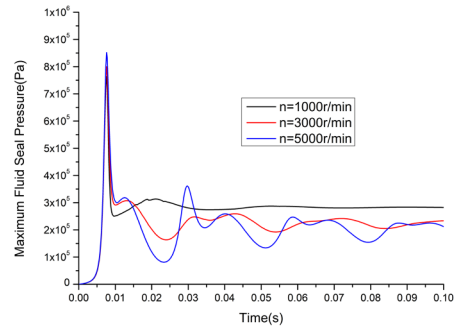**Figure 15.** The sealing force of gravity direction changes with time under different rotational speed



**Figure 16.** The maximum sealing pressure changes with time under different rotational speed

## 4. Conclusion

The results show that the maximum sealing pressure and sealing force of gravity direction will increase greatly in a very short time and then reduce rapidly. When sealing clearance increases, the displacement response amplitudes of axis trajectory, the maximum sealing force of gravity direction and maximum sealing pressure also increase. When liquid viscosity increases, the displace-

ment response amplitudes of axis trajectory, the maximum sealing force of gravity direction and maximum sealing pressure decrease. We also found that different rotor speed has almost no influence on the maximum sealing force of gravity direction and maximum sealing pressure.

## Acknowledgment

## References

[1] M. Arghir, J. Frene. Static and dynamic analysis of annular seals, Proc. of ASME Fluids Engineering Division Summer Meeting 2006, Miami, FL, USA. 2006: 517-526.

[2] Wenjie Zhou, Ning Qiu, Leqin Wang, et al. Dynamic analysis of a planar multi-stage centrifugal pump rotor system based on a novel coupled model[J]. Journal of Sound and Vibration, 2018, 434: 237-260.

[3] Congxin Yang, Pan Qiang, Sha An, et al. Effects of wear-ring clearance on performance of high-speed centrifugal pump[J]. Journal of drainage and irrigation machinery engineering, 2017, 35(1): 18-24. (in Chinese)

[4] Yan X., He K., Li J., et al. Nemerical techniques for computing nonlinear dynamic characteristics of rotor-seal system[J]. Journal of Mechanical Science and Technology, 2014, 28(5): 1727-1740.

[5] Jinkui Ma, Changhou Lu, Shujiang Chen. Simulation of Journal Centre Trajectories of Hydrodynamic Journal Bearing Under Transient Loads[J]. Journal of vibration, Measurement & Diagnosis, 2010, 30(1): 6-10. (in Chinese)

[6] Rao T, Biswas S, Hirani H, et al. An analytical approach to evaluate dynamic coefficients and nonlinear transient analysis of an hydrodynamic journal bearing[J]. Tribology transactions, 2000, 43(1): 109-115.

[7] Tichy J, Bou-Said B. Hydrodynamic lubrication and bearing behavior with impulsive loads[J]. Tribology Transactions, 1991, 34(4): 505-512.

[8] Zhen Li, Chnaglin Gui, Zhiyuan Li, et al. Study on Dynamic Behaviors of Variably-loaded Shaft-bearing System[J]. Machine design and Research, 2005, 21(1): 12-16. (in Chinese)

[9] Yan X., He K., Li J., Feng Z. P. A Generalized Prediction Method for Rotor dynamic Coecients of Annular Gas Seals. J. Eng. Gas Turbines Power, 2015, 13: 092506.

[10] ANSYS fluent 20.0 Theory Guide, ANSYS Inc., USA, 2019.