Effect of T-groove Parameters on Steady-state Characteristics of Cylindrical Gas Seal

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ABSTRACT. Gas film seal technology is becoming increasingly important as an advanced new rotary shaft seal technology in aviation engines and industrial gas turbines. In this paper the impacts of several parameters of T-groove cylindrical gas seal such as groove number, groove depth, groove width ratio, dam groove width ratio and floating ring length on the steady-state characteristics of cylinder film seal are studied in detail by the method of control variable using computational fluid dynamics software, and the focuses are on the pressure distribution, the gas film stiffness, and the leakage. Results show that with the increase of the number of grooves, the gas film stiffness increases gradually, but the leakage and leakage stiffness ratio decrease. The results also show that with the increase of groove depth, there is a maximum value for the gas film stiffness and a minimum value for leakage. This research plays an important role in guiding the design and the application of cylindrical gas seal.

Keywords: Gas Cylinder Film Seal, T-groove Parameters, Gas Film Stiffness, Leakage

1. Introduction

In the recent development of sealing technology, the new and advanced gas film seal technology is gaining more attentions in industrial gas and aviation engines turbines [1], since the gas film seal technology, comparing with other technologies, has lower leakage, wear, and energy consumption, but longer life expectation, simpler and more reliable operation [2]. Ma et al. carried out a series of researches on cylindrical gas seal and obtained results of gas film reaction force, film stiffness, and friction torque and seal leakage of the seal [3]. The dynamic characteristics of the cylindrical gas seal were also studied by the perturbation method [4]. Ma et al. further compared the performance of several common spiral groove forms and found that the cylindrical gas film seal is more suitable for sealing the key parts of the aero engine [5].

As a new structure of cylindrical gas seal, there is relatively few researches on the T-groove cylindrical gas seal. The T-groove cylindrical gas seal, therefore, is studied in this paper. The focuses are on the influence of T-groove parameters on the steady state characteristics of the cylindrical gas film by the control variable method. This research plays an important role in guiding the design and the application of cylindrical gas seal.

2. Model

2.1 T-groove cylinder gas film seal

Figure 1 illustrates the sketch of the expansion diagram of T-groove cylinder gas film seal. Sealing medium is air, and the detailed description of each parameter is presented in Table 1.

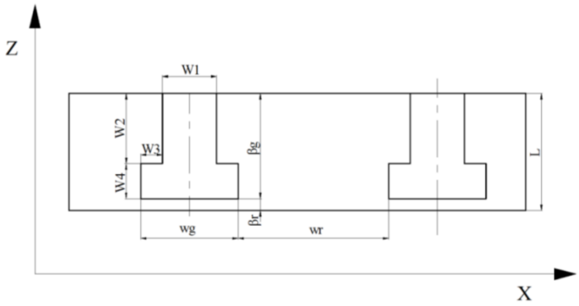


Fig.1 The sketch of the expansion diagram of T-groove cylinder gas film seal

Table1 Parameters definition

Parameter Type	Parameters(Unit)	Value
Slot parameters	Wg (mm)	5.73
	Wr (mm)	17.19
	Br (mm)	0.91
	Bg (mm)	9.09
Structural parameters	Static ring radius Rk (mm)	58.4
	Moving ring radius Rj (mm)	58.41
	Seal clearance c (μm)	10
	Eccentricity rate ε	0.5
	Eccentricitye (μm)	5
Operating parameters	Rotational speedn（r/min）	8000
	Pressure difference△P(MPa)	0.01
	Viscosity μ（Pa•s）	1.79×10^{5}

2.2 Model structure

First, the static and moving rings of T-groove gas film sealing were designed and established. The inner surface of the gas-film sealing static ring was processed with T-groove, and the parameters of the groove were shown in Table 1. Then the model of the T-groove gas film is built and illustrated in Figure 2.

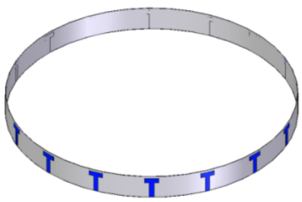
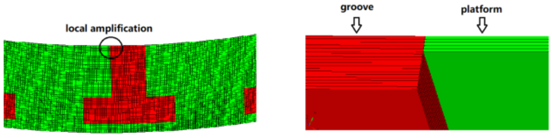


Fig.2 The model of the T-groove cylinder gas film seal

2.3 Mesh structure

To mesh the T-groove cylinder gas film seal, the HYPERMESH and ANSA are used in this paper. One important characteristics of the cylinder gas film seal is that the overall structure and the film thickness is very different, since the maximum dimension of the model is tens of millimeters, but the minimum dimension is only tens of microns. Therefore, the thickness direction should be classified as a dense grid.

Furthermore, a simple method for building the meshing cannot be used, since this might lead to poor quality mesh, which cannot satisfy the requirements of FLUENT calculation, and the results from simulation using the poor-quality mesh might be not accurate. As shown in Figure3, by using HYPERMESH and ANSA, the model is divided into two parts, the groove and the platform. In this paper, the hexahedral mesh structure is used, and the quality of the mesh is controlled by the method of meshing from surface to body. After the model is built, it is then not difficult to set up the boundary condition.



(a) Macro grid (b) Local grid

Fig.3 The mesh structure

2.4 Model assumptions

To perform the simulation and analysis, some assumptions of the model are necessary and described here. The first assumption is that the fluid film between the moving and stationary rings is a continuum medium and the Newtonian viscosity law is satisfied. The second assumption is that no relative sliding exists between the film and the moving/static ring's surface. The third one is that there is no disturbance and vibration, in other words, the film is stable. The forth assumption is that there is no pressure and thermal deformations during the process of operationThe last assumption is that both the volume and inertia forces are negligible.

2.5 Boundary conditions

Several boundary conditions are required, such as rotation speed of the moving ring, the moving and static ring walls, and the designated z axis. In this paper, the rotational speed is set to ω=8000rpm. The moving and static ring wall is set to wall motion and to stationary wall boundary condition, respectively. The rotation axis of the moving ring is used as the designated z axis.

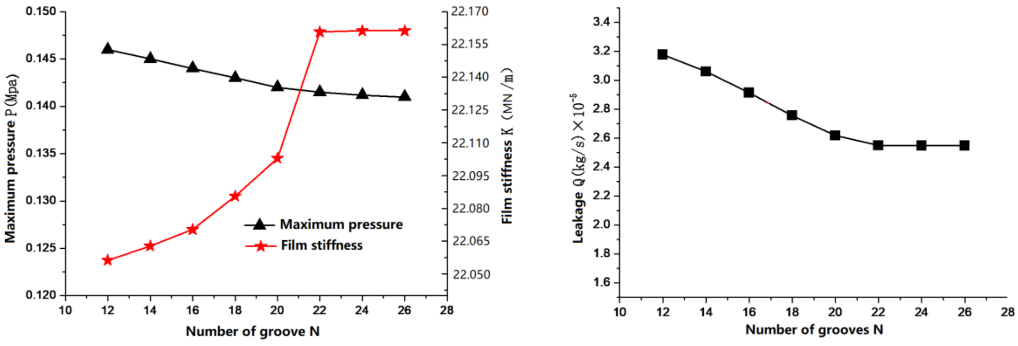
2.6 Solution set

Using FLUENT to simulate and analyze the sealing performance of gas film is feasible. The analytical method is accurate, and the result of analysis is reliability, and it has been verified in the literature [6-10].

3. Results

3.1 Effect of number of grooves

Figure 4 illustrates the relationship between the maximum pressures, the gas film stiffness, the leakage and the number of grooves. Figure 4(a) show that the maximum pressure decreases gradually when number of groove increases. When the number of grooves is 22, the maximum pressure tends to be stabilized. However, the film stiffness increases with the number of grooves. When the number of grooves reaches 22, the film stiffness tends to be stabilized. Figure 4(b) shows the effect of the number of grooves on the leakage. It can be seen from this figure that the leakage decreases when the number of grooves increases. This is because the hydrodynamic pressure effect is enhanced when the number of grooves is increased. Therefore, the pressure at the outlet is increased, and the leakage of the sealing gas is prevented. Since the leakage is gradually decreased, the sealing performance is improved.



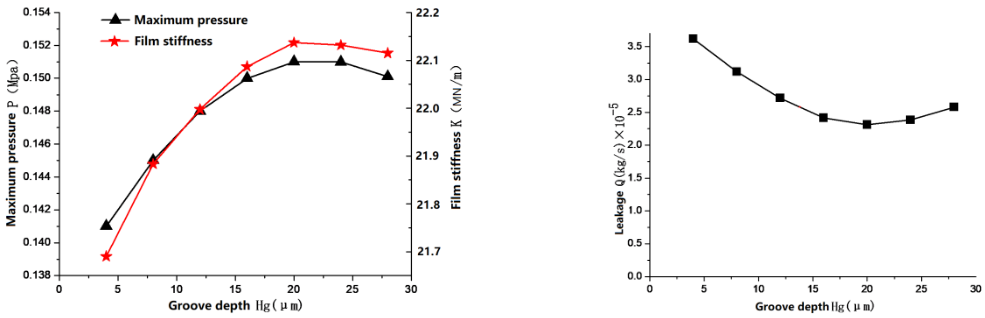
(a)

(b)

Fig.4 Effect of number of T-groove on the maximum pressure and the film stiffness (a) and the leakage (b)

3.2 Effect of groove depth

Figure5 shows the variation of the maximum pressure and the film stiffness (a) and the leakage (b) with the groove depth. The results in Figure 5(a) show that the maximum pressure and film stiffness reach maximum values simultaneously at the groove depth about 20μm, and then gradually decrease.



(a) (b)

Fig.5 Effect of groove depth on the maximum pressure and the film stiffness (a), and the leakage (b)

The impact of groove depth on the leakage is shown in Figure 5(b). It can be seen from the figure that the leakage reaches the minimum value when the groove depth is also about 20μm.This is due to that with the increase of the groove depth, the hydrodynamic pressure effect is enhanced, and then the leakage is reduced. However, when the depth exceeds 20μm, negative pressure zone is formed when gas flows through the groove. The reason is that the formation of the negative pressure zone makes the hydrodynamic pressure effect no longer increase. The sealing gap between the moving ring and the stationary ring increases when the groove depth increases. Therefore, the leakage begins to increase when the groove depth reaches more than 20μm.

3.3 Effect of groove width ratio (γ)

Figure6 shows that the response of the maximum pressure and the film stiffness change (a), the leakage

(b) to the groove width ratio. Results show that when the groove width ratio is 0.6, the maximum pressure reaches the maximum value, and then gradually decreases. The film stiffness increases with the increase of the groove width ratio. When the groove width ratio reaches about 0.5, the film stiffness tends to be stabilized.

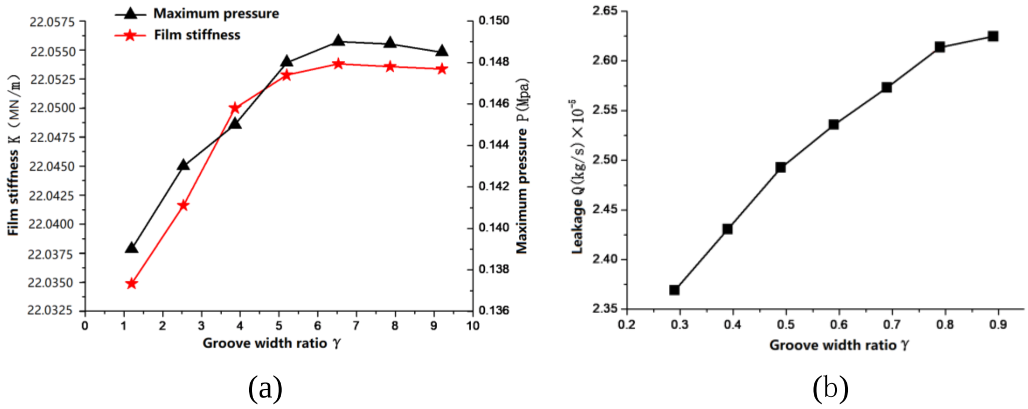


Fig.6 Effect of groove width ratio on the maximum pressure and the film stiffness (a), and the leakage (b**)**

Figure6 (b) shows the impact of the groove width ratio (γ) on the leakage. The leakage increases when the groove width ratio increases. This is because increasing of the groove width ratio causes increase of the sealing gap in the circumferential direction, which leads to higher leakage.

4. Summary

The effect of several parameters of the T-groove parameters on the sealing performance is investigated, and from the analysis, the following conclusions can be drawn:

1. The film stiffness increases when the number of grooves increases, and it tends to be stabilized when the number of grooves reaches 22. However, as the number of grooves increases, the leakage decreases. These indicate that when other parameters are constant, there are an optimal number of grooves. At the optimal number of grooves, both the leakage and the film stiffness reach the stable values.
2. With the increase of the groove depth, there is a maximum value of the film stiffness and a minimum value of the leakage. These two extreme values achieved simultaneously at the groove depth 20μm. These show that when other parameters are constant, there is an optimal groove depth. At this optimal groove depth, the leakage is reduced to the minimum value, and the film stiffness rises to the maximum value.
3. The film stiffness increases with the increase of the groove width ratio. When the groove width ratio is 0.5, the film stiffness tends to be stabilized, and when the groove width ratio is 0.6, the maximum pressure reaches the maximum value. The leakage increases when the groove width ratio increases. This is because increasing of the groove width ratio causes increase of the sealing gap in the circumferential direction, which leads to higher leakage.

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