ELSEVIER

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 23 (2011) 115 – 119

Procedia Engineering

www.elsevier.com/locate/procedia

2011 International Conference on Power Electronics and Engineering Application (PEEA 2011)

Analysis of Parameters and Performance for Spiral Grooved Cylindrical Gas Film Seal

Gang Ma[a], Wei Zhao[a], Xinmin Shen[a]a*

[a]School of Mechanical Engineering and Automation, Beihang University, Beijing, China, 100191

Abstract

Aimed at the downstream spiral groove structure in the cylindrical gas seal, the analysis and calculation were carried out with the change of different structure parameters and the stability performance of the seal. The three dimensional model of spiral groove cylindrical seal were built and simulated by Fluent. The hydrodynamic gas pressure distribution and the related regular curves including load, frictional torque and leakage were obtained with the change of seal structure parameters. The calculated results indicate that the gas film pressure shows as indention distributing and pressure peaks appear in the film thickness reducing area. Sealing structure parameters on the sealing stability performance have different effects, but the frictional torque is hardly influenced by spiral groove parameters. The recommended parameters of sealing structure are obtained.

Selection and/or peer-review under responsibility of [name organizer]

Key words: downstream spiral groove; cylindrical gas seal; stability performance; parameter analysis;

1. Introduction

With the improvement of the machine performance requirements, the demand of fluid dynamic seal for high-speed fluid machinery is also increasing. Because of its non-contact, low leakage, low wear characteristic and suitable for high-temperature environment, the research and application of gas film seal has become an important research direction for high-speed fluid machinery.

According to gas film sealing structure, the current study is sorted to two kinds, gas film face seal and gas film cylinder seal. The former has been widely used in a great numbers of ground equipment. With

* Corresponding author. Tel.: +086-13581924603;
E-mail address: sxxfzhw@163.com.

1877-7058 © 2011 Published by Elsevier Ltd. Open access under CC BY-NC-ND license.
doi:10.1016/j.proeng.2011.11.2475

deeply research of gas film seal application, cylinder gas film seal receives more and more attention because of its unique structural feature [1].

For the research of the cylinder gas film seal, Hendricks[2], Wilbur Shapiro[3,4] and Jed Walowit[5] have already made some progress. Currently, the research of cylinder gas film seal has across from laminar to turbulent flow [6,7]. The researchers in Mainland China (Jianping .Chen[8], Gang .Ma[9], Xiuhua .Li[10]) have done the preliminary research work in this field.

Groove geometric parameters would have significant effect on the performance of gas film seal. To study the parameters of spiral groove on influence of the seal stability characteristics and to provide theoretical guidance to the seal design，this paper carried out a comprehensive analysis and comparison of the structure parameter characteristics of downstream spiral groove cylinder gas film seal.

2. The flow boundary of gas film sealing

The assumptions: the sealed gas inside is ideal gas and is continuous medium agreed with Newton's law of viscosity; ignoring the gas volume force, inertia, effects of temperature and viscosity; the sealing ring is rigid and surface is smooth, and without relative slip between gas and sealing surface.

High pressure side is the gas outlet and low pressure side is the gas inlet. Set the surface of rotating and stationary ring into standard wall surface conditions and no slip velocity. The circumferential pressure equation is： $\overline{p}(\theta,\overline{z})=\overline{p}(\theta+2\pi,\overline{z})$ *(1)*

3. Numerical solution for boundary value problem

3.1. The basis of numerical computation

The basic hydrodynamic equations used in numerical calculation of the ideal gas film sealing are：

Continuity equation: $$\frac{\partial\rho}{\partial t}+\nabla\cdot(\rho V)=0 \quad (2)$$

Momentum conservation equation: $$\begin{cases}\dfrac{\partial(\rho u)}{\partial t}+\nabla\cdot(\rho uV)=-\dfrac{\partial p}{\partial x}+\dfrac{\partial\tau_{xx}}{\partial x}+\dfrac{\partial\tau_{yx}}{\partial y}+\dfrac{\partial\tau_{zx}}{\partial z}+\rho f_x\\ \dfrac{\partial(\rho v)}{\partial t}+\nabla\cdot(\rho vV)=-\dfrac{\partial p}{\partial x}+\dfrac{\partial\tau_{xy}}{\partial x}+\dfrac{\partial\tau_{yy}}{\partial y}+\dfrac{\partial\tau_{zy}}{\partial z}+\rho f_y\\ \dfrac{\partial(\rho w)}{\partial t}+\nabla\cdot(\rho wV)=-\dfrac{\partial p}{\partial x}+\dfrac{\partial\tau_{xz}}{\partial x}+\dfrac{\partial\tau_{yz}}{\partial y}+\dfrac{\partial\tau_{zz}}{\partial z}+\rho f_z\end{cases} \quad (3)$$

Where: ρ is fluid density; τ_{ij} is deviatoric stress component; f_i is quality force component; p is fluid pressure function; V is velocity vector; u、v、w are the velocity components in cartesian coordinates.

Energy equation: $$\frac{\partial}{\partial t}\left[\rho\left(e+\frac{V^2}{2}\right)\right]+\nabla\cdot\left[\rho\left(e+\frac{V^2}{2}\right)V\right]=\rho\dot{q}+\nabla\cdot(k\nabla T)-\nabla\cdot(pV)+\nabla\cdot(\tau\cdot V)+\rho f\cdot V \quad (4)$$

Where: e and $\frac{V^2}{2}$ stand for the internal energy and kinetic energy per unit mass; q stands for heat per unit volume; $\nabla\cdot(k\nabla T)$ is the imported quantity of heat; $-\nabla\cdot(pV)+\nabla\cdot(\tau\cdot V)$ is the power done by surface force; $\rho f\cdot V$ is the power done by the mass force.

The turbulence may form in the micro-gap three-dimensional flow field of gas film sealing due to the existence of the spiral groove, which may produce certain perturbation to the flowing. Thus, it is inaccurate to determine the flow state simply by Reynolds number. This paper using RNG k-ε turbulence model calculate the flow field of gas film sealing because it is a turbulence model for low Reynolds number.

3.2. Geometric model meshing and solution

Fig.1 is a geometric model of the downstream spiral groove cylinder gas film seal, the spiral groove is set in the surface of stationary ring. The gas film thickness changes along the circumferential direction due to the existence of eccentricity, so it is need to solve the entire region of gas film seal.

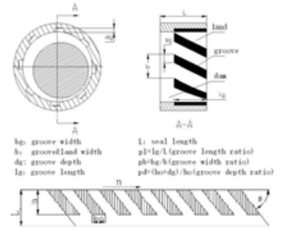

Fig.1 the structure model of the downstream spiral groove cylinder gas film seal

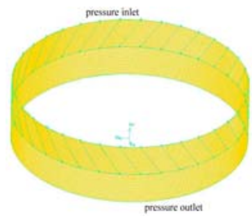

Fig.2 the computing regional grid

The grid is meshed by GAMBIT software. Because there are three kinds of regions (groove, land and dam) in gas film seal and it is extremely thin, the requirements for meshing are very strict. As gas film scale in the thickness direction varies greatly compared with other directions and taking into account the gas film sealing structure, it adopts sub-region meshing method, uses orthogonal hexahedral meshes when dividing the grid, meshes multi-grid in thickness direction and meshing from line, plane to volume.

Using the pressure-based implicit solver and the Reynolds averaged N-S equations as the governing equation; turbulence model uses the RNG k- ε model; pressure-velocity coupling uses SIMPLEC algorithm, pressure discretization is standard method and the momentum equations discretization are second-order upwind method.

4. The steady characteristics of the gas film sealing

Gas film steady characteristics mainly include loading force, seal leakage and friction torque.

Loading force

$$\left.\begin{aligned} F_r &= \int_0^l \int_0^{2\pi} (p - p_a) R_j \cos\theta d\theta dz \\ F_t &= \int_0^l \int_0^{2\pi} (p - p_a) R_j \sin\theta d\theta dz \\ F &= \sqrt{F_r^2 + F_t^2} \end{aligned}\right\} \quad (7)$$

Seal leakage

$$Q = 2\int_0^{2\pi} \rho \left(-\frac{h^3}{12\eta}\frac{\partial p}{\partial z} \right) R_j d\theta dz \quad (8)$$

Friction torque

$$M = \int_0^l \int_0^{2\pi} \left(\frac{\partial p}{R_j \partial\theta}\frac{h}{2} + \eta\frac{\omega R_j}{h}\right) R_j^2 d\theta dz \quad (9)$$

5. Numerical example and sealing performance analysis

Table 1 basic test parameters in reference [8]

parameters	value	parameters	value
Radius (mm)	20	Groove width ratio δ	0.5
Seal width L (mm)	19	Groove depth ratio γ	3
Groove number n	18	Groove length ratio Lg	1.0
Groove spiral angle α (º)	65		

For verifying the validity of the analysis method, implemented an example: compared with the experimental results of radial cylindrical spiral groove gas film seal [8]. The test parameters are shown in table 1, eccentricity ε = 0.4, film thickness ho = 10um. The calculated results are consistent with the experimental results (as shown in figure 3), which illustrates that the calculation method is feasible.

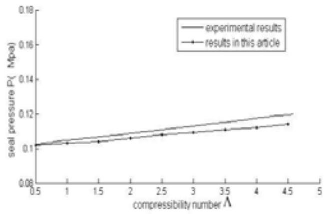

Fig.3 Example of comparison

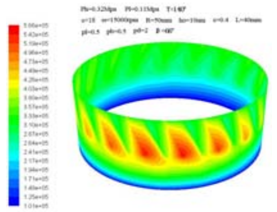

Fig.4 Three-dimensional pressure field distribution

5.1 .Pressure field distribution

Computation analysis of the seal structure is carried out under different parameters (groove spiral angle β, groove depth ratio p_d, groove width ratio p_b and groove length ratio p_l).

The three-dimensional pressure field distribution of downstream spiral groove cylinder gas film is shown in Figure 4. Because stairstep effect, the pressure field is jagged in the spiral groove region, pressure peaks appear in the film thickness reducing area and the peaks number is equal to the number of grooves.

5.2. The influence of groove parameters on stability performance

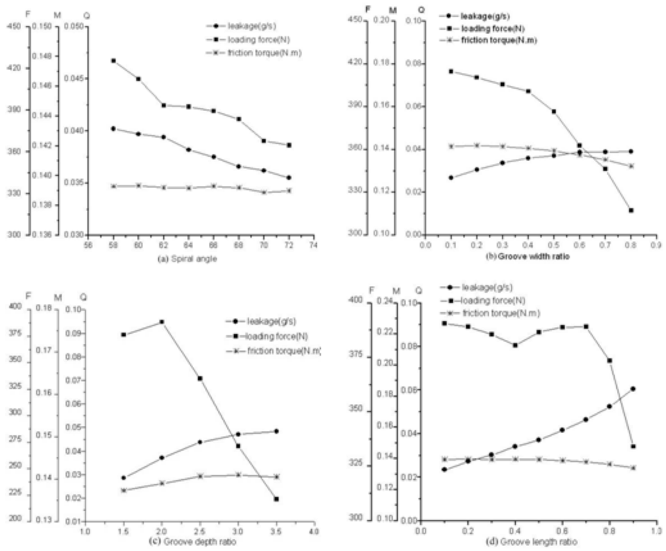

Fig.5 the influence of spiral groove parameters on stability performance

Figure 5 (a) shows the influence of spiral angle on stability performance. The impact of spiral angle to leakage and friction torque is not obvious, but loading force change greatly when spiral angle is less than 62^o. The recommended spiral angle should be 62^o.

Figure 5 (b) shows the influence of groove width ratio on stability performance. With increasing of groove width ratio, the leakage increase while loading force and friction torque reduce, but it does not obviously affect friction torque. The recommended groove width ratio should be 0.4~0.5.

Figure 5(c) shows the influence of groove depth ratio on stability performance. With increasing of groove depth ratio, leakage and friction torque increase, but friction torque is not affected apparently. The loading force increases with the increasing of groove depth ratio when it is smaller than 2; but the loading force decreases sharply when groove depth ratio is greater than 2.

Figure 5(d) shows the influence of groove length ratio to stability performance. The loading force has little change when groove length ratio is less than 0.7, but it decreases rapidly when groove length ratio is greater than 0.7. It is better the groove length ratio should be 0.2~0.6.

6. Conclusion

The pressure of downstream spiral groove cylinder gas film seal shows as indention distributing and pressure peaks appear in the film thickness reducing area.

Sealing structure parameters on the sealing stability performance have different effects, but frictional torque is hardly influenced by spiral groove parameters (spiral angle, groove depth ratio, groove width ratio and groove length ratio). In order to achieve a good sealing effect, it is recommended to take the spiral angle 62^{o}, groove depth ratio 2, groove width ratio 0.4~0.5 and groove length ratio 0.2~0.6.

Acknowledgements

This work was financially supported by National Natural Science Foundation (51075018) of China.

Reference

[1]Gang Ma, Xinmin Shen. Development and Analysis of Advanced Gas Film Sealing Technology[J]. Aeronautical Manufacturing Technology, 2009(3):58-61. In Chinese

[2]Robert C. Hendricks. Straight Cylindrical Seal for High-Performance Turbomachines.NASA-1850, 1987.

[3]Wilbur Shapiro. Numerical, Analytical, Experimental Study of Fluid Dynamic Forces in Seals[R]. NASA/CR-2004-213199/VOL2,2004.

[4]Wilbur Shapiro. Users' Manual for Computer Code GCYLT[R].NASA/CR-2003-212362, 2003.

[5]Jed Walowit, Wilbur Shapiro. Numerical, Analytical, Experimental Study of Fluid Dynamic Forces in Seals[R] . NASA/CR -2004-213199 /VOL3, 2004.

[6]Mihai Arghir and Jean Frene. Analysis of a Test Case for Annular Seal Flows[J],Journal of Tribology. Transaction of the ASME, 1997,119:408-414

[7]J.M.Darden, E.M.Earhart and G.T.Flowers, Experimental Rotordynamic Characterization of Annular Seals Facility and Methodology[J], Journal of Engineering for Gas Tubines and Power. ASME. 1999, 121:349-354

[8]Jianping Chen, etc. Radial Cylindrical Spiral Groove Gas Seal Theoretical and Experimental Research [J]. Journal of Beijing University of Aeronautics and Astronautics, 2000, 26(4):439-442. In Chinese

[9]Gang Ma, Guangzhou Xu, Xinmin Shen. Design and Analysis for Spiral Grooved Cylindrical Gas Seal Structural Parameter [J]. Lubrication Engineering, 2007, 32(4):127-130. In Chinese

[10]Xiuhua Li. Study of Interface Structure and Properties of Gas Film Cylinder Seal[D]. Beihang University, 2010:22-38. In Chinese