Proceedings of the Seventeenth (2007) International Offshore and Polar Engineering Conference
Lisbon, Portugal, July 1-6, 2007

ISBN 978-1-880653-68-5; ISBN 1-880653-68-0(Set); ISSN 1098-6189 (Set)

Numerical Analyses of a Spiral Groove Dry Gas Seal Under Slip Flow Conditions

Xiao-ni Yin
Offshore Oil Engineering Co. Ltd. Engineering Company
Tianjin, China
Xu-dong Peng
School of Mechatronic Engineering, University of Petroleum of China,
Hangzhou, Zhejiang, China

ABSTRACT

A finite element program for the spiral dry gas seal under slip flow conditions is designed based on the modified Reynolds Equation. Making u se of a rule of getting larger film stiffness while maintaining lower lea-kage rate, the effects of the face geometric parameters on the static beh-avior of the S-DGS are analyzed under slip flow conditions. Compared with the computed result without considering slip flow, it shows that t-he groove length ratio, groove depth and helical angle have large influ-ence on the seal performance, but the number of spiral grooves and gro-ove width ratio have little influence on that under slip flow conditions.

KEY WORDS: spiral groove; dry gas seal; analysis of seal behavior; slip flow

INTRODUCTION

In petrochemical industry and other services, the rabbling reaction kettle is one of the key equipments, which have wide application. Its problem about shaft seal is a key factor that has effects on production efficiency and product quality, and has been needed to be improved urgently. A dry gas face seal (DGS) used for kettles is the typical representative of dry gas face seals at low speed. Calculated by Finite Element Method(FEM), the slip flow has the large influence on the performance, such as opening force, film stiffness and leakage when the spiral-groove dry gas face seal (S- DGS) is operating at lower sealed pressure (0.101MPa $<p_o<$0.303MPa) and at this speed(n<6000rpm). Without considering slip flow especially when Knudsen number is between 0.05 and 1, there is appreciable error with the fact[1]. Thus, for rabbling reaction kettle, the influence of the slip flow on the performance must be considered.

Now that the influence of the slip flow on performance of S-DGS must be considered in above operating condition, it's necessary to study the effects of surface geometric parameters on the performance, which compare with the effects without considering the slip flow. Then design theories of S-DGS can be more perfect. By the further research of main parts of S-DGS systems for the low process parameters, the theoretical support can be offered for the engineering design and application of S-DGS.

ANALYTICAL MODEL

Assuming nominally flat, and parallel sealing faces, and neglecting curvature effects, and considering the first-order slip-flow boundary condition, the first-order modified Reynolds equation to study the slip flow, derived from the Navier-Stokes equations and the continuity equation has the form[2]:

$$\frac{\partial}{\partial\theta}\left(ph^3\frac{\partial p}{\partial\theta}(1+6\frac{\lambda}{h})\right)+r\frac{\partial}{\partial r}\left(ph^3\frac{\partial p}{\partial r}(1+6\frac{\lambda}{h})\right)=6\mu wr\frac{\partial ph}{\partial\theta} \quad (1)$$

Eq. (1) is written in nondimensional form as

$$\frac{1}{R^2}\frac{\partial}{\partial\theta}\left(PH^3+6K_nH^2\right)\frac{\partial P}{\partial\theta}+\frac{1}{R}\frac{\partial}{\partial R}\left(RPH^3+6K_nRH^2\right)\frac{\partial P}{\partial R}=\Lambda\frac{\partial PH}{\partial\theta} \quad (2)$$

Defination: $R = r/r_i$, $H = h/h_1$, $P = p/p_i$, $\Lambda = 6\mu\omega r_i^2/(p_i h_1^2)$, $Kn=\lambda_i/h_1$.
where:

r = radius of seal surface;
h = gas film thickness;
h_1 = gas film thickness of non-grooved region;
p = gas film pressure;
μ = dynamic viscosity;
ω = angular velocity;
Λ = compressibility number;
Kn = Knudsen number;
λ_i = molecular mean free path;
i and o = parametric values of seal inner and outer radius separately.

A Galerkin formulation was utilized in order to apply the Finite Element Method to Eq. (2)

$$\iint\left[H^3\left(\frac{\partial P^2}{R\partial\theta}\frac{\partial\delta P}{R\partial\theta}+\frac{\partial P^2}{\partial R}\frac{\partial\delta P}{\partial R}\right)-2\Lambda PH\frac{\partial\delta P}{\partial\theta}+12KnH^2\left(\frac{\partial P^2}{R\partial\theta}\frac{\partial\delta P}{R\partial\theta}+\frac{\partial P^2}{\partial R}\frac{\partial\delta P}{\partial R}\right)\right]RdRd\theta=0 \quad (3)$$