附件 2　　浙江水利水电学院“南浔青年学者”申请表

<table>
<tr><td>姓　名</td><td>宋源森</td><td>出生年月年龄（年龄）</td><td>1993 年 7 月岁
（ 31 岁）</td><td>参加工作时间</td><td>2024 年 5 月</td></tr>
<tr><td>现所在单位（部门）</td><td>机械工程学院</td><td>最高学历/学位</td><td>博士</td><td>专业技术职务</td><td>讲师</td></tr>
<tr><td>符合条款</td><td colspan="5">符合科研类，中科院 TOP1 区 1 篇，SCI 期刊论文 2 篇，国内一级期刊（浙大标准）1 篇，绩点 110</td></tr>
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绩点：_____</td><td colspan="4"></td></tr>
<tr><td rowspan="4">科研类
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<tr><td colspan="4">Song Y S, Bai S X, Yang J, et al. Fluid cavitation intensity in zero leakage upstream pumping face seals with spiral grooves[J]. International Journal of Applied Mechanics, 2023. (SCI 二区期刊, IF: 3.5)</td></tr>
<tr><td colspan="4">Song Y S, Bai, S X. Thermal cavitation effect on the hydrodynamic performance of spiral groove liquid face seals[J]. Materials, 2024. (SCI 一区期刊, IF: 3.1)</td></tr>
<tr><td colspan="4">白少先，宋源森．液体密封端面倾斜椭圆孔上游泵送特性[J]．摩擦学学报, 2019. (国内一级期刊（浙大标准）)</td></tr>
<tr><td>人才称号类
绩点：_____</td><td colspan="4"></td></tr>
<tr><td>总绩点</td><td colspan="4">110</td></tr>
<tr><td colspan="5">备注：请严格按照《浙江水利水电学院“南浔青年学者”实施办法（试行）》（浙水院〔2022〕114 号）附件《业绩成果绩点赋值项目库》的类目、分类、等级（等次）、绩点填写。</td></tr>
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<tr><td>所在单位（部门）意见</td><td colspan="5">1.经审核，申请人所填内容：□属实　　□不属实；
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#	作者	标题	来源出版物	文献类型	入藏号
1	**Song, YS**; Bai, SX	Thermal Cavitation Effect on the Hydrodynamic Performance of Spiral Groove Liquid Face Seals	***MATERIALS*** 2024, 17 (11): 2505.	J Article	WOS:001245467700001
2	**Song, YS**; Bai, SX; Yang, J; Chen, JJ	Fluid Cavitation Intensity in Zero Leakage Upstream Pumping Face Seals with Spiral Grooves	***INTERNATIONAL JOURNAL OF APPLIED MECHANICS*** 2023, 15 (10): 27.	J Article	WOS:001073576200003
3	Bai, SX; **Song, YS**; Yang, J	Elastic deformation of liquid spiral groove face seals operating at high speeds and low pressure	***INTERNATIONAL JOURNAL OF MECHANICAL SCIENCES*** 2022, 226: 107397.	J Article	WOS:000818003900002
				合计	3

备注 影响因子/期刊分区的年份选择：最新年份

收录文献附录

第 1 条，共 3 条：
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作者： Song, YS (Song, Yuansen); Bai, SX (Bai, Shaoxian)
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所属机构： Zhejiang University of Technology
通讯作者地址： Bai, SX (corresponding author), Zhejiang Univ Technol, Inst Proc Equipment & Control Engn, Coll Mech Engn, Hangzhou 310032, Peoples R China.
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SCIE	METALLURGY & METALLURGICAL ENGINEERING *in SCIE edition*	20/90	Q1	2023
SCIE	MATERIALS SCIENCE, MULTIDISCIPLINARY *in SCIE edition*	208/439	Q2	2023
SCIE	PHYSICS, APPLIED *in SCIE edition*	63/179	Q2	2023
SCIE	PHYSICS, CONDENSED MATTER *in SCIE edition*	32/79	Q2	2023

SCIE	CHEMISTRY, PHYSICAL *in SCIE edition*	90/178	Q3	2023

第 2 条，共 3 条:
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作者: Song, YS (Song, Yuansen); Bai, SX (Bai, Shaoxian); Yang, J (Yang, Jing); Chen, JJ (Chen, Junjie)
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所属机构: Zhejiang University of Technology
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作者: Bai, SX (Bai, Shaoxian); Song, YS (Song, Yuansen); Yang, J (Yang, Jing)
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作者地址: [Bai, Shaoxian; Song, Yuansen; Yang, Jing] Zhejiang Univ Technol, Coll Mech Engn, Hangzhou 310032, Peoples R China.
所属机构: Zhejiang University of Technology
通讯作者地址: Bai, SX (corresponding author), Zhejiang Univ Technol, Coll Mech Engn, Hangzhou 310032, Peoples R China.
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SCIE	MECHANICS *in SCIE edition*	5/170	Q1	2023

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宋源森
期刊指标综合报告

数据库：期刊引证报告（1997 年 - 2023 年），期刊引证报告（1997 年 - 2023 年）	作者姓名：宋源森 作者单位：浙江工业大学 机械工程学院	检索人：彭梅芳 检索日期：2024年11月19日

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检索人：彭梅芳

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Elastic deformation of liquid spiral groove face seals operating at high speeds and low pressure

Shaoxian Bai *, Yuansen Song, Jing Yang

College of Mechanical Engineering, Zhejiang University of Technology, Hangzhou 310032, China

ARTICLE INFO

Keywords:
Liquid face seal
Elastic deformation
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ABSTRACT

The uneven distribution of fluid pressure in the spiral groove area leads to the elastic deformation of the seal faces, which not only affects the sealing performance but also affects the running stability. In this paper, a numerical model of a high-speed spiral groove liquid face seal is proposed with the consideration of elastic deformation and cavitation medium compressibility. The novelty of this study is that the pressure of the cavitation region is modeled as an uneven distribution rather than as a constant. This uneven pressure distribution of sealing surfaces is generally regarded to have an influence on face deformation. Based on the assumption that the fluid exists at a complete gas state in the cavitation, the elastic deformation and pressure distribution of sealing surfaces are calculated. The influence of elastic deformation on sealing performance is further investigated. Results show that the elastic deformation of sealing surfaces and cavitation effect has a significant influence on the stability of sealing clearance, which may produce a negative effect on the sealing performance of liquid face seals. The face deformation causes a divergent gap between two seal faces. With the increase of rotational speed, the elastic deformation of sealing surfaces reduces at low seal pressure but increases at higher seal pressure, which may influence the cavitation behavior and pressure distribution of surfaces. Furthermore, the sealing performance of spiral groove liquid face seal becomes more complicated because of the coupling effect of cavitation effect and elastic deformation. The changing trend of sealing performance is different under various seal clearance and seal pressure. The obtained results may provide guidance for the future design of liquid face seals in engineering applications under high-speed conditions.

1. Introduction

The liquid spiral groove face seal, as a kind of non-contact shaft seal, has been widely used in rotating machinery [1–4]. Generally, due to the hydrodynamic effect of face spiral grooves [5], a micron-scale clearance is generated to separate the seal faces of the rotor and stator during the operation [6]. The stability of this clearance between the seal faces is the key to ensuring the safe and reliable operation of the seal. However, this stable clearance is easily influenced by the elastic deformation of sealing surfaces [7–14], which may have a significant impact on sealing performance and even result in sealing failure, especially considering the cavitation effect [15–17]. More attention has been attracted to investigating the elastic deformation of sealing surfaces, which is beneficial to predicting sealing performance and optimizing the design.

In 1999, Baheti and Gkirk [18] analyzed the ring distortion of a high-pressure liquid seal and noted that the pressure difference between the inside and outside of the seal ring was the main cause of mechanical deformation, and this deformation was conical. When the supply pressure was 1.48 MPa, the vertical deflection of the inside and outside of the seal ring were 0.0009 and 0.0080 mm, respectively. With the growth of seal pressure, the deflection demonstrated a similarly increasing trend. Afterward, the thermoelastohydrodynamic analysis of radial conical mechanical seals was conducted by Thomas et al. [19,20] and the results showed that the surface deformation significantly changed the geometric shape and sealing performance of gas face seals. Elastic deformation could cause convergence deformation of seal clearance and change the pressure field.

In addition, the groove arrangement of sealing surfaces also presents a significant influence on the sealing characteristics of liquid face seals. For example, a numerical analysis was conducted by Luo [21] to study the effect of waviness, taper, and groove type on the sealing performance. This study showed that the groove position arrangement had different influences on the opening force under the influence of the change of face structure. Alfredo [22] adopted the experimental method to investigate the deformation behavior of gas face seals under different

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Fluid Cavitation Intensity in Zero Leakage Upstream Pumping Face Seals with Spiral Grooves

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Cavitation intensity variations in fluid lubrication may alter the mechanical and lubrication properties of the fluid. In this paper, a compressible cavitation model is presented to study the effect of fluid cavitation intensity on zero-leakage flow of upstream-pumping spiral grooves face seals (UPSGLFS). The pressure variation in cavities can be calculated considering the compressibility of the lubricating medium, the ratio of minimum pressure to cavitation pressure is further defined to characterize the cavitation intensity. A numerical analysis of the zero-leakage behavior of UPSGLFS is then performed based on its effect. Results show that cavitation plays a negative role in sealing performances. However, the groove's configuration and working conditions have substantial effects on controlling the cavitation intensity. Meanwhile, whether a circumferential continuous pressure ring above the seal pressure can be formed is the design basis for judging the strict zero leakage of the medium, rather than only depending on the change of leakage rate parameter value. With suitable spiral groove parameter design, zero-leakage design for upstream-pumping seals may be achieved under multi-speed and multi-seal-pressure conditions. Here, a zero-leakage map is presented for working conditions with multi-speed ranging from 500 to 20,000 rpm and multi-seal pressure ranging from 0.1 to 3.0 MPa.

Keywords: Liquid lubrication; fluid cavitation intensity; zero leakage; upstream pumping flow; spiral groove seal.

1. Introduction

Upstream pumping face seals, in particular liquid spiral-groove face seals, have been widely applied to strictly control medium leakage, so as to ensure the reliable and safe operation of petroleum, petrochemical, and aerospace power equipment

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Article

Thermal Cavitation Effect on the Hydrodynamic Performance of Spiral Groove Liquid Face Seals

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Abstract: Cavitation in micro-scale lubricating film could be determined by the fluid's thermal properties, which impacts the hydrodynamic lubrication capacity dramatically. This study aimed to novelly investigate the impact of the thermal cavitation effect on the hydrodynamic performance of liquid face seals, employing the compressible cavitation model, viscosity–temperature effect, and energy equation. The finite difference method was adopted to analyze the thermal cavitation by calculating the pressure and temperature profiles of the lubricating film. The working conditions and geometric configuration of liquid face seals under different thermal cases were further studied to explore their effects on sealing performance. The results showed that thermal cavitation could reduce the temperature difference of liquid film at high speeds, and cavitation would be weakened under temperature gradients, which further dropped off the hydrodynamic performance. Contrary to the leakage rate, the opening forces tended to be lower with the increasing seal pressure and film thickness under high-temperature gradients. Furthermore, apart from the spiral angle of grooves, the hydrodynamic performance exhibited significant variation with increasing groove depth, number, and radius at high-temperature gradients, which meant that the thermal cavitation effect should be considered in the design of geometric grooves to obtain better hydrodynamic performance.

Keywords: thermal cavitation effect; liquid lubrication; hydrodynamic performance; cavitation; liquid face seals

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1. Introduction

The liquid face seal [1–3] (LFS), serving as a critical element in rotary power machinery, can ensure the long life and reliable operation of the equipment as a result of the hydrodynamic performance of lubricating film improved by the surface textures (such as spiral grooves [4], dimples [5], etc.). Meanwhile, cavitation is a complex mechanism in the lubrication analysis due to various inducing factors and the weakened hydrodynamic performance produced, especially at high speeds [6,7]; and its complexity further increases when the thermal properties of the cavitation medium are involved [8,9]. In the current engineering practice, the equipment gradually develops for high working parameters (high speed, high temperature, etc.), and the thermal cavitation effect cannot be ignored to better predict the serviceability and optimize the design.

In fact, the behavior of the seal can be significantly influenced by thermal effects at high rotation speeds. For example, the utilization of thermocouples integrated within the stationary ring, as demonstrated by Denny [10] in 1961, revealed a significant increase in facial temperature by several tens of degrees. In addition, Orcutt [11] employed a pyrometer to conduct temperature measurements of the rotor surface. The observed temperature gradient along the radial direction could exceed 10 K. The above findings were subsequently validated by Tournerie et al. [12] through the utilization of thermography as a technique. As observed by Doust and Parmar [13], a small inclination of the sealing ring happened due to the variations in surface temperature, resulting in their acquisition of a tapered

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液体密封端面倾斜椭圆孔上游泵送特性

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(浙江工业大学 机械工程学院, 浙江 杭州 310032)

摘　要: 气液异相介质隔离密封的实现有赖于密封端面几何型槽的上游泵送特性, 为探索多孔端面实现液封气密封的设计途径, 对液体密封端面倾斜椭圆孔上游泵送特性开展研究. 考虑空化效应, 采用有限差分方法对转速、密封间隙、密封压力等操作参数和孔深、倾斜角、方向因子、孔数等结构参数对开启力和泄漏率的影响规律进行了数值分析. 结果显示: 液体润滑条件下端面倾斜椭圆孔可产生明显的上游泵送效应, 增加周向孔数和方向因子可实现被密封介质的完全零泄漏, 同时可产生明显的流体动压效应使端面开启力提高50%以上. 文中密封压力条件下, 孔深取5~10 μm, 倾斜角取45°, 周向孔数大于80, 方向因子大于3时, 密封可实现完全反向泵送, 反向泄漏率的增加与随着孔数、方向因子和孔深的增加而增加.

关键词: 端面密封; 液体润滑; 椭圆孔; 上游泵送; 空化效应
中图分类号: TH117.2　　**文献标志码:** A　　**文章编号:** 1004-0595(2019)01–0010–07

Upstream Pumping Characteristic of Inclined-Ellipse-Dimples on Liquid-Lubricated Seal Face

BAI Shaoxian*, SONG Yuansen

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Abstract: The realization of the gas-liquid heterogeneous medium isolation seal depends on the upstream pumping characteristics of the geometric groove of the sealing face. In order to explore the design approach of the liquid sealing gas seal for the porous face, the upstream pumping characteristic of inclined-ellipse-dimples on liquid seal face was theoretically analyzed. Considering the cavitation effect, the finite difference method was used to numerically analyze the influences of operating parameters (e.g. rotation speed, seal clearance and seal pressure) and the structural parameters (e.g. dimple depth, inclination angle, slender ratio and dimple number on the open force and leakage rate). Results show that the inclined-ellipse-dimple liquid face seals may present significant upstream pumping and hydrodynamic effects, which led to open force improved more than 50% greater in the analysis. A complete backward leakage may be achieved by the inclined-ellipse-dimple upstream pumping face seals by increasing dimple number and slender ratio. A complete backward leakage can be achieved under pressure condition in the cases of 5~10 μm dimple depth, 45° inclination angle, greater than 80 dimple number and greater than 3 slender ratio. Meanwhile, the increase in reverse leakage rate increased with the dimple number, slender ratio, and dimple depth.

Key words: face seal; liquid lubrication; ellipse-dimples; upstream pumping; cavitation effect

发动机等动力机械装备密封处于复杂的油、气工作介质环境, 通过端面型槽的上游泵送作用将油液或气体从低压侧泵送到高压侧可实现对油、气介质的有效隔离, 即实现"油封气"或"气封液"异相流体密封, 而采用微孔型槽设计有利于进一步提高密封端面的耐磨性. Lebeck[1]的直线槽上游泵送密封试验研究表明,

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证 明

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