Experimental and numerical analysis of heat transfer and thermal deformation in small-dimension liquid mechanical seals

Amine Ben-Abdelwahed, Shaolin Liu *, Alain Sommier, David Reungoat

Univ. Bordeaux, CNRS, INRAE, Bordeaux INP, I2M, UMR 5295, USC 1368, F-33400, Talence, France
Arts et Métiers Institute of Technology, CNRS, INRAE, Bordeaux INP, I2M, UMR 5295, F-33400, Talence, France

Keywords:
Thermodynamic modeling
Mechanical seal
Numerical simulations
Experimental study
Lubrication

A B S T R A C T

This paper presents an experimental and numerical analysis of heat transfer and thermal deformation in small-dimension (1.4 mm) liquid mechanical seals operating in an unstable dynamic tracking mode. The studied non-contacting mechanical seal is used in a liquid pump for turbojets. The study aims to estimate the values of pressure, temperature, and thermal deformations that can prevent excessive wear of the sealing rings and control the increase in leakage rate or power loss during operation. Experimental investigations were conducted under a nominal inner pressure of 0.7 MPa, across a wide range of rotational speeds (from 1000 to 6000 rpm), and at low Reynolds numbers (Re < 70). Two high-viscosity fluids, glycerol and engine oil, were used as sealing fluids. Rotational speeds and inner pressure were set as boundary conditions in the simulations. Temperatures measured by thermocouples during the experiments were used to compare with the simulation results. Simulations were performed using the computational fluid dynamics (CFD) software COMSOL. The two-dimensional numerical models accounted for thermal transfers and face seal deformations, coupled with the pressure field in the lubrication fluid. The effects of various sealing fluids and rotational speeds on the time-dependent behavior of temperature, displacement, and pressure within the thin liquid lubricant film were investigated. Subsequent comparisons between experimental and numerical results, particularly for temperature data measured by thermocouples under various operating conditions, demonstrated strong consistency. The greatest discrepancy observed was less than 1.2 °C.

1. Introduction

Mechanical seals are used to contain pressurized fluids in rotating machinery such as pumps and compressors, where the operating conditions (pressure, temperature, and velocity) prevent the use of elastomeric seals [1]. A mechanical seal consists of a rotating ring (rotor) mounted on the shaft and a stationary ring (stator) fixed to the housing [2]. The contact between the two rings is maintained by elastic components (such as springs) and the pressure of the sealed liquid, while the secondary seals ensure proper sealing (Fig. 1). Optimal operating conditions are obtained when the sealing rings are slightly separated by a thin liquid film, only a few micrometers thick, which provides high wear resistance and a low leakage rate.

During the operation of the rotor, an important conversion of mechanical energy into heat occurs. As a result, heat flux is generated in the thin liquid film [3]. The heat flux is transferred to the sealing rings and then to the surrounding liquid. The amplitude of thermal phenomena depends on numerous factors, such as the correct alignment of the sealing rings [4], pressure of the sealed liquid [5], and heat transfer conditions [6]. Furthermore, a high-temperature gradient is responsible for a change in the physical properties of the sealed liquid, which may lead to its vaporization in the thin liquid film and thermal deformations of the sealing rings. This will negatively affect the operating conditions for which the seal was designed. Therefore, the study of the temperature distribution in the sealing rings is of great importance in determining the performance of the mechanical seal [7,8].

Numerous studies on the thermal effects of non-contacting mechanical face seals have been conducted over the past few decades [9–12]. The main objective of these studies was to measure or theoretically determine the temperature distribution in the lubricant liquid, within the sealing rings, and the heat transfer in the surrounding fluid. A brief review is presented below. For instance, Lebeck [12] described the complexity of heat transfer mechanisms in mechanical seals. Because of the complex environment surrounding the seal, the heat transfer paths are multiple, leading to heat flow computation complications. In their studies, Buck [13] and Brunetiere et al. [14] confirmed the assumptions made by Lebeck [12], including the premise that most of

* Correspondence to: Arts et Métiers Institute of Technology, 33400, Talence, France.
E-mail address: shaolin.liu@u-bordeaux.fr (S. Liu).

https://doi.org/10.1016/j.ijheatmasstransfer.2025.126754
Received 9 November 2024; Accepted 22 January 2025
Available online 3 February 2025