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Experimental study of two-phase mechanical face Seals with laser surface texturing☆

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ABSTRACT

Two-phase mechanical face seals with laser surface texturing (LST) on their end faces were investigated using a test rig with a transparent rotating ring. Cavitation occurred in some of the dimples and annular vaporization regions attached to the dimples were observed. The speed limit of the LST seals with suitable parameters was obviously higher than that of a seal with a plain end face, while those with sub-optimal LST parameters exhibited a lower speed limit. These results reveal that LST shows potential in two-phase mechanical face seals, but the LST parameters should be carefully considered.

1. Introduction

When mechanical face seals are used in environments with high-pressure hot water or light hydrocarbons, the liquid phase leaked through the gap in the seal is likely to vaporize. The large difference between the energies of the liquid and vapor phases and the ability of the vaporization process to adsorb latent heat cause great changes of pressure distribution and temperature on the seal face, which harms the performance of mechanical face seals [1]. The literature contains many reports of unstable phenomena of mechanical face seals such as puffing, popping open and oscillating. Nau [2] recorded significant periodic fluctuation of friction torque and leakage of mechanical face seals under unstable operating conditions. Lebeck and Chiou [3] observed that there was no visible leakage in two-phase mechanical face seals and the friction torque decreased with increasing chamber temperature rising up to a certain value, after which it increased sharply. Orcutt [4] used a quartz rotor against a carbon stator to seal water. He observed that a concentric ring located close to the atmosphere side reflected different brightness during the course of seal operation. Because water has a different index of refraction from that of air or water vapor, the brighter region was assigned to water vapor. The vapor region became larger as the inlet temperature was raised, and got smaller when the inlet temperature was lowered. The extent of thin film vaporization was closely related to the seal interface temperature. This is the first confirmation of vaporization at an interface in the open literature. Based on Orcutt's observations, Hughes [5], Lebeck [6], Yasuna and Hughes [7] and Etsion and Pascovici [8–11] developed analytical models for two-phase mechanical face seals. Lebeck pointed out that “There is an opportunity here to do some basic research on how to model two-phase flow in narrow channels” [1].

Plain end faces are commonly used in two-phase mechanical face seals. This end face structure generates a large amount of friction power during operation. Common practices followed to avoid seal rings from overheating are to increase flush rate or to set up complex cooling devices so that the vaporized area can be narrowed. However, these methods increase the cost of design, manufacture, operation and maintenance to a large extent as well as not directly improve the lubrication of the seal interface.

A grooved end face has proved to be a successful technique to improve the lubrication of friction pairs and the performance of two-phase mechanical face seals. Netzel [12] found that grooved seal faces could substantially improve the performance of two-phase mechanical seals and decrease the amount of wear, but caused a large amount of leakage. Harrison and Watkins [13] reported similar results for two-phase mechanical face seals with grooved faces.

Laser surface texturing (LST) has the advantages of reducing friction and increasing load capability compared with those of flat surfaces, and has been successfully applied to all-liquid and all-gas mechanical face seals [14]. Etsion and coworkers have conducted a large amount of theoretical and experimental work on both of LST liquid and gas seals. Etsion and Burshtein [15] first developed

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an analytical model to predict the performance of all-liquid non-contacting mechanical face seals with regular micro-dimples, showing that the preferable percentage of pores was 20%. Etsion et al. [16] presented theoretical and experimental results of LST mechanical face seals for use in water pumps. The experimental results obtained using a test rig were well predicted by the theoretical model. The textured faces improved the performance of the water pump seals. Etsion and Halperin [17] also investigated mechanical face seals with partially textured surfaces. The LST seals showed a substantial reduction in friction torque by more than 50% compared with that of the untextured seals. McNickle and Etsion [18] used LST seals to enhance the performance of a high-speed gas turbine engine. Their experimental results showed the potential benefits of the near-contact gas seal in terms of smoother running, lower friction torque, and lower face temperature at high velocity compared with conventional seals with plain faces. Then, Etsion and coworkers developed different methods of analysis to study the mechanism of LST gas mechanical face seals and optimized their performance in terms of maximum film stiffness combined with minimum gas leakage [19–21]. Qiu and Khonsari [22] experimentally investigated the friction of LST thrust bearing under different speeds and load. Their results showed that the samples with textured surfaces provide a lower coefficient of friction than untextured surfaces. Brunetière and Tournerie [23] presented a deterministic numerical study of textured mechanical face seals operating in the mixed lubrication regime. The mechanism of generating load on the rough-textured surface was analyzed and the effects of texture density and aspect ratio were also studied. Because all-liquid and all-gas mechanical face seals with LST have remarkable tribological performance, it is logical to investigate the application of LST to two-phase mechanical face seals.

In this paper, the performance of two-phase mechanical face seals with LST was examined experimentally. By considering friction torque and temperature at the internal diameter (I.D.) along with the analysis of phase distribution at the seal interface, we are able to discuss the feasibility of two-phase mechanical face seals with LST.

2. Experiment

2.1. Test rig

A test rig with an internal pressurized mechanical face seal was used in the experiments, as shown in Fig. 1. The rotating ring was transparent and dimples were manufactured on the stationary ring end face so that the liquid-vapor distribution at the seal interface could be observed. The shaft was driven by a servo motor. The rotating ring was fixed on the shaft end by a leveling screw device consisting of three uniformly distributed bolts. The stationary-ring assembly is shown in the lower part of Fig. 1. The stationary ring was fixed by a M6 bolt, which was also used to adjust the initial coning of the seal end face. A constant closing force generated by a spring-loaded device was applied to the bottom of the stationary-ring assembly through a ceramic ball. The chamber was connected to inlet and outlet flush pipes. The physical properties of the flow were precisely controlled by a complex hot-water system.

The test rig contained four sensor modules, as illustrated in Fig. 1(a). A load cell was used to measure the force generated by the spring load device. A PT100 thermal resistor was positioned at the inner radius of the stationary ring to measure the seal interface temperature. An SLR Camera (CANON D60 with a 100 mm macro-lens) was used to monitor the phase change and phase distribution in the seal gap. An S-type pressure sensor was located between the stationary ring assembly and vertical holder to measure the friction torque. Different from typical measurement of dynamic torque, the test rig was measured static torque on the stationary ring, which improved the accuracy of torque measurement because it effectively avoided interference from the bearing torque.

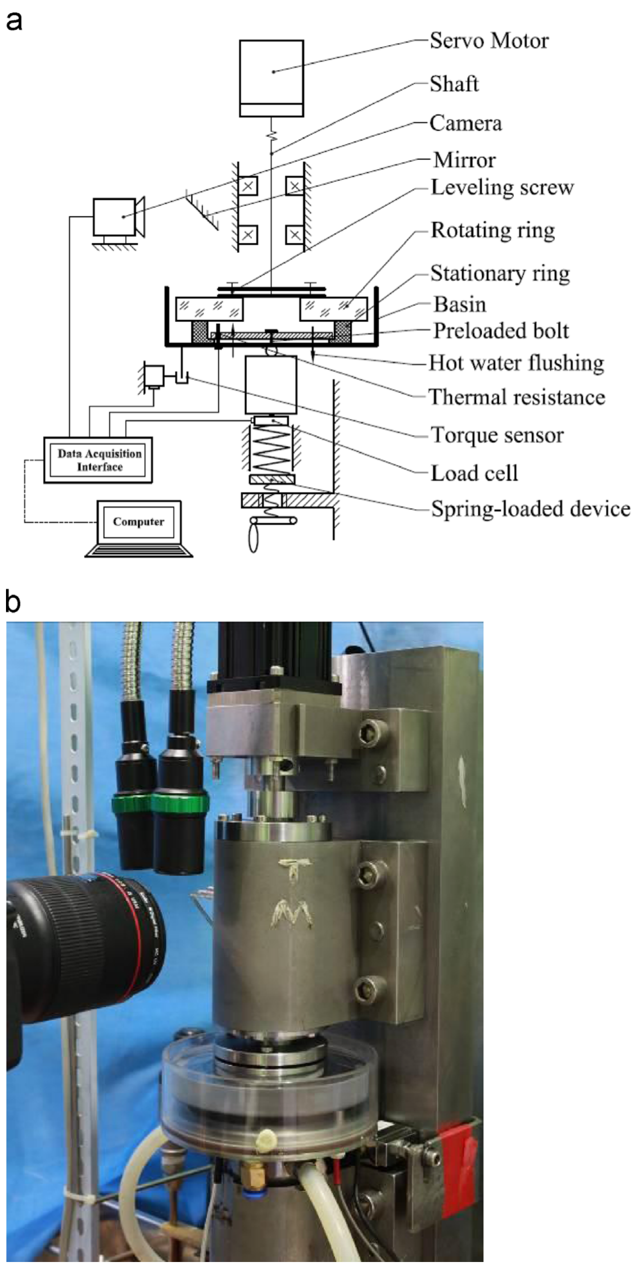

Fig. 1. (a) Schematic diagram and (b) photograph of the test rig used to examine the two-phase mechanical face seals with LST.

2.2. Preparation of seal rings

The stationary ring with an I.D. of 80 mm, outer diameter (O.D.) of 100 mm and thickness of 15 mm was made of carbon graphite (Schunk, Germany, grade: FH82Z5), as shown in Fig. 2(a). The rotating ring with an O.D. of 120 mm and thickness of 15 mm was made of high-quality quartz (Beijing KingLass Quartz Company in China, Grade: JGS1, flatness of end faces $<0.3\ \mu m$, $SiO_2 > 99.95\%$), as shown in Fig. 2(b).

Firstly, the end faces of stationary rings were lapped to a flatness of less than 0.6 μm and average surface roughness (Ra)