THERMO-MECHANICAL DEFORMATION IN HEAT SINK SEAL RINGS

Lyndon Scott Stephens  
Associate Professor  
stephens@engr.uky.edu

Matthew A. Hayden  
Research Associate  
mahayd0@engr.uky.edu

Bearings and Seals Laboratory, University of Kentucky  
151, RGAN Bldg, Lexington, KY-40506-0503, USA, Ph: (859)257-6336 x80679, Fax: (859)257-3304

ABSTRACT
Heat sink mechanical seals use a heat exchanger built directly into the stationary seal ring to control the temperature at the seal interface. This paper presents the latest analytical and experimental results showing the thermal deformation of the heat sink seal at the sealing interface. The results show that the virgin interface contact pattern (before wear) is non-conformally convex with point contact towards the outer diameter. These results are discussed in relation to positive and negative coning that is found in conventional seal rings.

INTRODUCTION
Temperature control of the sealing interface in mechanical seals has been identified as one of the most critical factors affecting seal performance [1]. Many different approaches to interface temperature control have been investigated and implemented throughout the historical development of mechanical seals. Most of these approaches have relied on controlling the temperature and properties of the fluid in the seal chamber by introducing cooling loops and flush fluids. These approaches essentially change the convective thermal boundary condition at the seal outer diameter. Still other approaches have utilized double or tandem seals which introduce a buffer fluid at the inner diameter of the primary seal. These approaches allow one to change the convective thermal boundary condition at the seal inner diameter in addition to the outer diameter. In both cases, the seal interface temperature essentially becomes dominated by the conductive thermal resistance between the interface and the inner and outer diameter, resulting in a non-uniform temperature distribution and local hot spots.

In 1997, Stephens and Kelly [2] proposed a new approach to mechanical seal cooling that utilizes a micro heat sink that is fabricated integrally with the mechanical seal stationary ring and located within microns of the sealing interface. Figure 1 illustrates the design, which consists of replacing the solid stationary ring in a conventional seal design with a stationary ring that has a porous section comprised of highly structured cooling pins. The cooling pins separate the “base” of the stationary ring from the “cover” portion of the stationary ring to form a pin fin heat sink. An external coolant is then circulated through the gland plate to the outer diameter of the stationary ring, radially through the heat sink section exiting at the stationary ring inner diameter, and finally routed out of the gland. Note that the heat sink coolant is completely separated from the process fluid using two o-rings on the stationary ring OD and ID. The advantages of such a design are numerous and include: 1) a very small conductive thermal resistance between the interface and the cooling fluid; 2) a very large convection coefficient due to the pin fin design of the heat sink and 3) a largely uniform temperature distribution across the interface.

Previous work found in [3]-[6] has documented the details of the seal design and have shown its ability to control the seal interface temperature to within a few degrees of the cooling fluid temperature even under extreme conditions such as dry running and dead heading of the pump. This technical brief analyzes the thermally induced deformation in the heat sink seal rings, presents experimental results that support the analysis results and discusses the ramifications of this deformation profile with respect to sealing performance.
RESULTS

A finite element model of the heat sink seal detailed in [6] was used to predict the thermal deformation of both the rotating and stationary rings at the seal interface. Figure 2 shows a typical result for the case of the seal operating in a dry running condition (no fluid in the seal chamber) and 1 LPM of water circulating through the heat sink at room temperature. Under these conditions, the friction power generation at the seal interface is 60 W and the maximum seal interface temperature is predicted to be 55.4 °C as compared to about 180 °C for the same conditions with a conventional seal. As Figure 2 indicates, both the rotating carbon graphite ring and the stationary WC coated nickel heat sink ring have convex deformation profiles resulting in a non-conformal contact point at a location towards the outer diameter of the rotating ring. If one defines the amplitude of the convex pattern as the maximum distance between the stationary and rotary faces under deformation, then the predicted amplitude is 450 nanometers. Under such contact, the softer carbon graphite ring would be expected to wear, creating a groove less than 450 nanometers.

Figure 3 shows the corresponding experimental result which is a 3-D surface profile of the carbon graphite rotating ring after testing it in a centrifugal pump under the same conditions as those used in the analysis. Clearly, a dominant groove is seen towards the outer diameter as predicted by the analysis. The surface characterization indicated the depth of the groove to be 500 nanometers, again supporting the validity of the analytical results.

DISCUSSION

The results in this paper neglect any deformation induced by mechanical effects such as retaining devices and sealed fluid pressure. In conventional seals these mechanically induced deformations result in non-conformal interface contact where only the outer diameters of the rings touch. This is termed negative radial taper or “negative coning”. Also for conventional seals, thermal deformation alone results in non-conformal interface contact where only the inner diameters of the rings touch. This is termed positive radial taper or “positive coning”. Since all mechanical seals leak, conventional wisdom advocates designs where positive coning is greater than negative coning such that the sealed fluid, which enters the interface on the seal OD, easily lubricates the interface.

By contrast the heat sink seal still has negative coning due to mechanical deformation and has the convex interface contact pattern induced by its unique thermal properties as shown in Figure 2. Note, though, that the finite element results show that the amplitude of the heat sink seal thermal deformation is much smaller than the typical negative coning found in conventional seals. So much so that one can argue the heat sink seal remains essentially flat as compared to the mechanically induced negative coning. The conclusion, therefore, is that mechanically induced negative coning dominates in heat sink mechanical seals, creating questions as to the ability of the sealed fluid to provide lubrication to the seal interface. The counterpoints are twofold: 1) experiments using the heat sink seal in a water pumping application showed no visible leakage during more than 150 hours of testing, and 2) since the heat sink seal can effectively cool the interface, there is less need for the sealed fluid to provide lubrication. Further studies in this area are planned.

REFERENCES