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Simulation of a hydraulically controllable reactor coolant pump seal

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ABSTRACT

A hydraulically controllable mechanical seal for a nuclear reactor coolant pump (RCP) is under development. Its purpose is to correct excessive or insufficient leakage through RCP seals, a current expensive problem. The non-rotating seal face contains an annular cavity, filled with pressurized fluid. By changing the pressure within the cavity, the deformation and geometry of the face can be changed. Since the face geometry determines the thickness of the lubricating film between the two seal faces and the leakage rate, the leakage rate can be controlled. Simulations indicate that the hydraulically controllable seal provides sufficient control to address many abnormal leakage rate scenarios.

1. Introduction

The reactor coolant pump (RCP) mechanical seal plays a critical role in nuclear reactors. The key to its long life and high reliability is continual full film lubrication, with the avoidance of excessive leakage and the avoidance of mechanical contact between the seal faces (insufficient leakage). Therefore such seals are designed to operate with a specified finite, but thin, lubricating film. However, occasionally excessive or insufficient leakage is experienced, which is indicative of major seal degradation. This is commonly caused by electrophoresis (deposition of iron oxide particles on the seal faces), pump transients, and temperature and pressure excursions in the pump/seal system. In extreme cases this can require a reactor shutdown. To mitigate such abnormal leakage rates, there are very few options under plant operator control without shutting down and servicing the seal, an expensive undertaking. Common procedures involve changing the seal injection water temperature, and swapping seal injection filters in the case of electrophoresis. This limited number of mitigation options has motivated interest in the development of a controllable seal, with a means of active control of the leakage rate.

In the past, two different approaches to a controllable mechanical seal have been considered. In the first approach, the closing force on the floating seal face is controlled [1,2]. This is done by applying a closing force on the floating face (to regulate the film thickness) with a hydraulic actuator. However, there is a distinct disadvantage of this approach. When used with a purely hydrostatic seal, if the seal coning becomes negative (diverging gap between the faces), the seal will be unstable and very difficult to control.

In the second approach, the preferred approach, the opening force on the floating seal face is controlled [3–5], to control the film thickness. This is done by controlling the face geometry. One method is to vary the coning for flat face surfaces. This method is based on the fact that the pressure distribution in the lubricating film, with coned flat surfaces, depends on the coning, and the thickness of the lubricating film is proportional to the coning for a fixed closing force.

This can be seen from the curves in Fig. 1, a typical plot of the dimensionless film pressure versus radial location. Each curve corresponds to a given value of the dimensionless coning. Only the curves for positive values of coning are of interest, as negative values result in instability. The dimensionless film pressure is the pressure divided by the pressure at the OD. The coning δ is defined as the difference in the film thickness (gap width) at the OD and ID, and the dimensionless coning δ^* is the coning divided by the film thickness at the ID, δ/h_i. The area under each curve is proportional to the opening force on the seal face, which is equal to the closing force under equilibrium conditions. Therefore each curve corresponds to both a particular value of the dimensionless coning and a particular value of the closing force. For a fixed value of the closing force, the dimensionless coning, δ/h_i, is a constant. Thus, the film thickness is proportional to the coning.

Within the seal an actuator is used to deform one of the seal faces so as to alter the coning. The produced deformation compensates for the natural mechanical and thermal deformation to which the seal is subjected, and can be regulated to generate a desired amount of coning. If the film

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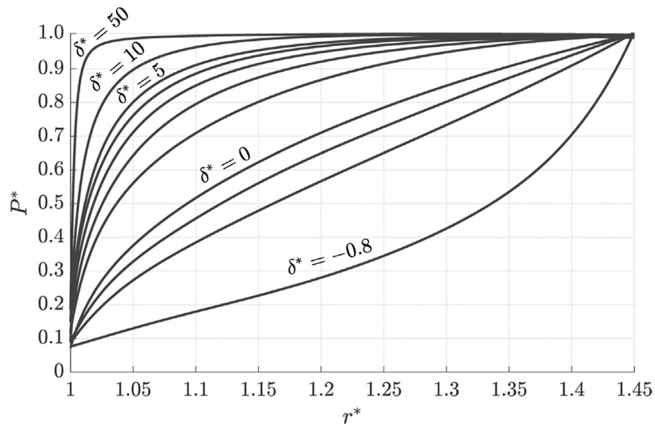

Fig. 1. Pressure profiles, coned flat surfaces.

thickness is too small and face contact is imminent, the coning is increased to increase the film thickness. If the film thickness is too large and the leakage is excessive, the coning is decreased to return the leakage to an acceptable level. It is important to note that the force which keeps the two seal faces separated and the film intact is produced by the pressure distribution in the film. The actuator regulates this force by controlling the coning. Thus, very precise control of the film thickness can be achieved. It is also important to note that this approach is applicable to both hydrostatic and hydrodynamic seals, since the latter always contains a hydrostatic component. Two prototype seals based on the second approach in which the coning is varied had been developed several years ago. These utilized piezoelectric actuators. The first was for a boiler feedwater pump [3] while the second was for a liquid oxygen turbopump [4,5].

In the present study, the feasibility of a controllable RCP seal is assessed. Due to the nuclear environment, piezoelectric actuators are not suitable due to their required high voltages. Therefore a seal with hydraulic actuation is considered.

2. Conceptual design

To assess the feasibility of a controllable RCP seal, the Westinghouse #1 RCP Seal has been selected as a hypothetical subject for conversion to a controllable seal. Fig. 2 shows the Westinghouse seal assembly with the proposed non-rotating controllable seal face outlined and labelled "simulated face." The "ring" denotes the non-rotating, floating face, while the "runner" denotes the rotating, axially-fixed face.

The proposed controllable seal face is shown in Fig. 3. It is made of 410 stainless steel, and is slightly pre-coned. The hydraulic actuator is integral with the face, and consists of an annular cavity filled with fluid. Within this cavity, a hydraulic pressure is applied, which induces a downward deflection of the lower face surface, opposing the upward deflection caused by the RCP-induced pressure distribution in the lubricating film. The net local force distribution determines the local deflection distribution. Thus, the applied pressure deforms the face and adjusts the surface geometry of the seal face, which affects the pressure distribution within the lubricating film and the leakage rate. The hydraulic pressure is provided by the discharge of the RCP, or a dedicated hydraulic pressure source. The cross-sectional shape of the cavity has been chosen to optimize the cavity pressure-leakage rate characteristics.

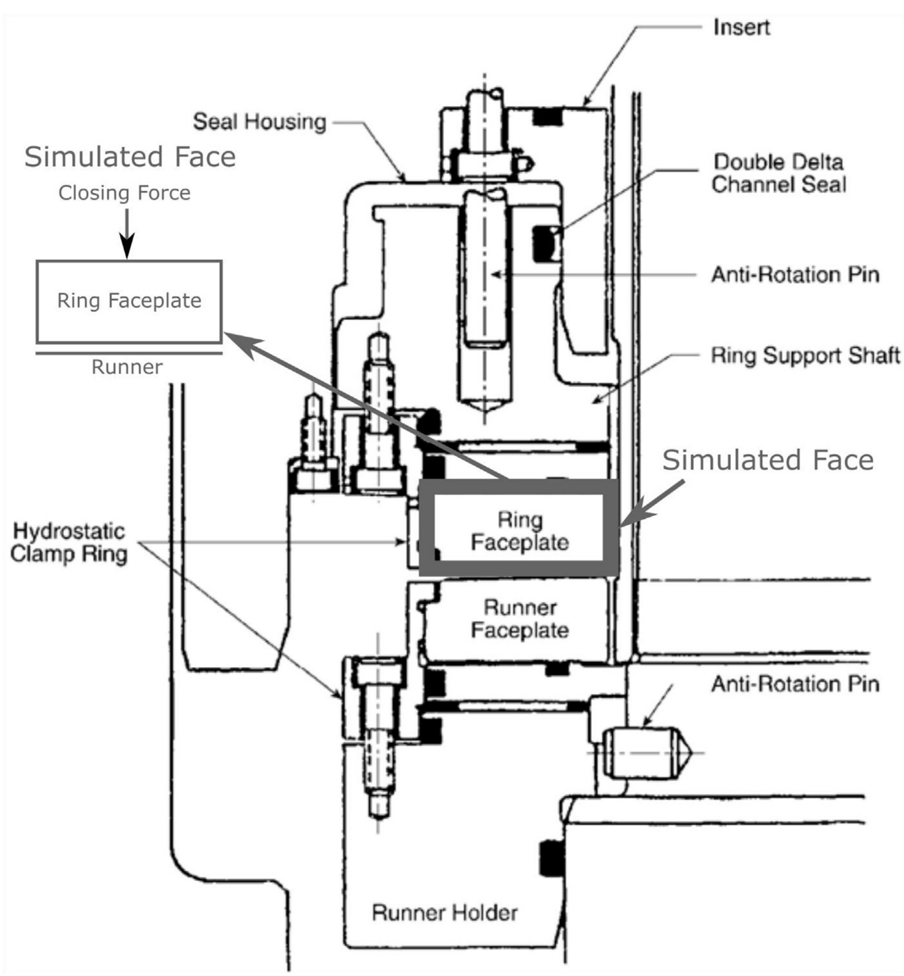

Fig. 2. Westinghouse #1 RCP seal.