Rotordynamics and Signature for Diagnostics of a Mechanical Face Seal Subject to Rubbing Contact

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ABSTRACT

Mechanical face seals are incredibly complex mechanisms where a proper design requires knowledge of lubrication, seal dynamics, and thermal effects, among others. This complexity in design, along with uncertainties in operation, manufacturing, and installation, results in a machine component which has previously been described as the most unpredictable machine element. Experimental, industrial, and intuitive experience led previous researchers and practitioners to venture undesirable seal face contact as a possible route to failure. For the first time, this work investigates analytically the problem of seal face contact as a condition present during steady-state operation. Common machine faults such as misalignment or imbalance instigate seal vibration, and lead to undesirable and unforeseen contact between the seal faces. Persisting rubbing contact causes face wear and fatigue, excessive leakage, and ultimately seal failure. Earlier research investigating this phenomenon has so far been heuristic and/or experiential, lacking the rigor which could be provided via robust theoretical modeling and numerical simulation that incorporates realistic contact of rough surfaces. The objective here is to implement recent developments in modeling rotor-stator rub using recent modeling of rough surface contact, which is employed to simulate rubbing phenomena in a flexibly-mounted stator mechanical face seal intended to operate in a non-contacting regime. Specifically, the elastoplastic model for rough surface contact developed by Jackson-Green is employed to quantify the contact force between the seal faces, using real (i.e., measured) surface roughness and material parameters. This method allows for asperity contact and fluid-film to co-exist in a mixed lubrication regime and ensure that the seal face clearance remains positive. Numerical simulation of the equations of motion indicates several common modes of contacting operation, where the contact is identified using seal dynamic waveforms, frequency spectra, and contact force calculations.

In some cases, particularly for large seal face coning and small misalignments, the FMS seal face response with contact qualitatively resembles that encountered during non-contacting operation; in these cases, reliably detecting the onset of contact may be difficult, and as a consequence prolonged operation may result in damage to the inner radius surface of the seal ring. In other cases involving

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coned-face FMS seals, contact is observed to generate a significant nonlinear aperiodic response, the hallmark signatures of which could be used to quickly diagnose contact to the seal faces. In the most extreme case, a flat-faced seal is observed to quickly suddenly and catastrophically bifurcate into a response where extreme deflections and contact forces would assuredly result in expedient seal failure. In such a case, failure occurs so quickly that no current condition monitoring could permit the machine to be shut down prior to failure; thus, to avoid this scenario the designer should include some initial coning apart from that generated via thermal deformation.

Though previously known via intuition or experience, this work for the first time analytically demonstrates a possible mechanism by which seals fail via severe contact. Considerations for seal face contact diagnostics are discussed, along with possible directions for future work. As such, much work remains towards understanding dynamic contact between the faces of a hydrodynamic mechanical face seal. First, this work did not account for shaft speed or pressure differential transients which are encountered during system start-up and shut-down. Understanding seal behavior during this regions is critical towards better designs avoiding contact and better diagnostics to quickly detect contact when it does occur. In a similar manner, previous work has shown that thermal deformations during these transients is an integral component of seal operation; the present study should be expanded to include heat generation due to viscous and friction effects, and then provide a method for using those effects to determine the transient coning of the seal.