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Undesired acoustic emissions of mechanical face seals: Model and simulations

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ABSTRACT

Mechanical face seals are used with most types of mechanical equipment, thus understanding the behavior of sealing systems is required for improved performance. The present paper investigates a type of seal utilized in automotive cooling water pumps, which, under particular service conditions, generates undesired acoustic emissions and manifests malfunctioning. The problem is examined through a lumped parameter model together with a mixed friction tribological model. Numerical simulations demonstrate that the phenomenon is caused by the insurgence of stick-slip vibrations during shaft deceleration. In addition, the stability threshold is investigated and the influences of some design parameters are evaluated.

1. Introduction

Mechanical seal is a device that helps join systems or mechanism together preventing leakage, containing pressure, excluding contamination. The applications for industrial products are innumerable such as for pumps, mixers, dryers and other specific equipment (e.g. [1–6]). In this paper an outside pressurized mechanical face seal in silicon carbide (SiC) and carbon with a primary rotating ring and a spring mechanism needed to hold the annular surfaces together, is investigated (shown in Fig. 1). It is used in automotive applications, having water as a cooling liquid.

The mechanical face seals are usually composed of two mainly flat rings, in relative motion, separating a pressurized fluid from the atmosphere, with a compression spring and a drive mechanism. Typically, they run in a mixed lubrication region defined by a given value of the duty parameter G [7]. However, if the leakage rate of the seal rises, hydrodynamic lubrication takes a part in the sliding contact. In any case, seals may operate in any of the following three lubrication regimes according to A.O. Lebeck's principles [1]:

- Full film lubrication: seals develop a significant film thickness, so that the entire load is supported by fluid pressure. In such cases, almost no touching occurs, friction is low, and there is very little wear.
- Mixed lubrication: this is probably the most common operation mode for many seals. Mixed friction is characterized by the fact that a part of the load is carried by actual mechanical contact, even though the majority of the load may be carried by fluid pressure.
- Boundary lubrication: is characterized by the situation where either the quantity of present lubricant is so small, or speeds are so low that fluid pressure has not developed. Even in this case, some small fraction of the load may be carried by fluid pressure, if more than just a surface layer of lubricant is present. However, the resulting excessive mechanical contact between the two seal faces leads to high frictional heat generation rates, as well as high friction induced stress on the seal faces.

The individuation of some behaviors and the development of models are useful in many cases, during their design, in order to forecast performance. Dayan et al. [8] and Zou et al. [9] simulated the dynamics of mechanical face seals and studied the sensitivity of the relative misalignment to prevent possible contact between surfaces. Brunetiére et al. [10] and Brunetiére and Tournerie [11] have presented numerical analysis of the behavior of a mechanical seal solving the Reynolds equation operating in a mixed lubrication regime. Brunetiére and Apostolescu have proposed a semi-analytical analysis of mechanical face seals: the model takes account of thermal effects and face distortions [12]. Several authors have developed numerical-thermo-elasto-hydro-dynamic

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Fig. 1. Mechanical face seal.

models in non-contacting mechanical face seals [13,14]. Researchers used acoustic emissions in order to detect incipient seal failure [15,16]. Salant [17] has indicated that the use of a train of ultrasonic wave packets provides an effective means of detecting the collapse of the lubricating film between seals.

In this paper, the authors analyze the problem of the seal that under particular conditions exhibits unwanted noise (ringing) together with malfunctioning. Experimental results show that the noise is related to friction torque and reveals the poor seal functioning. Ringing phenomena in mechanical face seals are rarely studied because of the difficulty in reproducing these phenomena.

Anyway, Nau [18] describing the mechanical seal face materials and discussed the failure modes including the 'ringing'. Hirabayashi et al. [19] investigated the causes of 'ringing phenomena' as a consequence of the blow-off of boiling liquid near the sealing surfaces. Kiryu et al. analyzed experimentally the phenomena in [20–22] where they reached the conclusions that the acoustic emissions ('ringing') were generated by 'stick-slip' phenomena due to both the lubrication regime of the seal and the dynamic characteristics of the rotating shaft system.

Based on A.O. Lebeck's theory [1] and on the results of numerical simulations obtained by a lumped parameter model, the present paper supports the hypothesis that stick-slip phenomenon occurs, according to the conclusions of Kiryu et al. [20–22]. Stick-slip, as explained in detail in several papers [23–28], is a phenomenon, of intermittent movement caused by friction force, depending on speed and on the mechanical properties of the system. Many authors have dealt with the problem in various ways, however, in recent studies, the friction force has been considered as a function of the relative speed between the surfaces in contact. Subsequently, experimental tests and mathematical models have demonstrated that stick-slip is due to deceleration motion [29–31].

2. Position of problem and experimental evidence

According to technical documents and experimental tests, the analyzed mechanical face seal presents the ringing phenomenon, which is observable when there are shaft deceleration and low running shaft speed. Such a statement is compatible with the stick-slip hypothesis: an intermittent movement due to the friction forces function of speed, in combination with the mechanical characteristics of the system (inertia, stiffness and damping) [23–28]. The test rig, mounting the examined seal, is shown in Fig. 2. Experimental tests have reproduced the phenomenon obtaining some measures.

In addition, in Fig. 5 the diagram temperature-shaft speed displays the zone where the studied seal rings. The authors have indicated some points on the main boundary line.

Fig. 3 shows the friction torque and Fig. 4 the acoustic emissions during a test at 500 rpm with a fluid temperature of 70 °C. It is possible to see that the maximum peak of frictional torque is 304 Hz, corresponding to the resonance frequency of the seal. A thing to notice is that the association of the torque friction with the corresponding measured acoustic emissions. Thus it can

Fig. 2. Test rig.

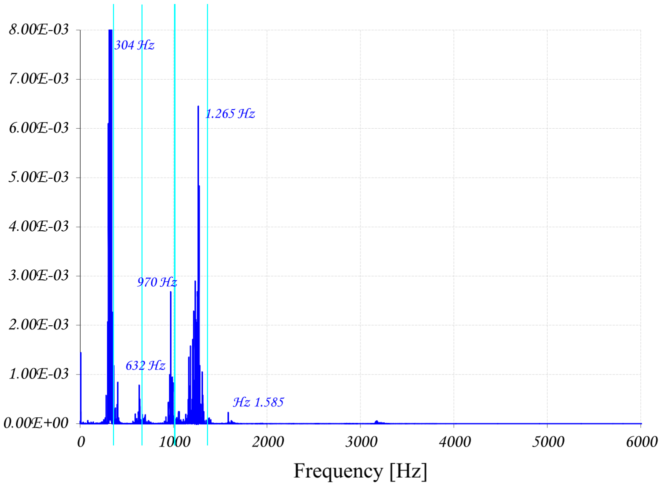

Fig. 3. Spectrum of friction torque.

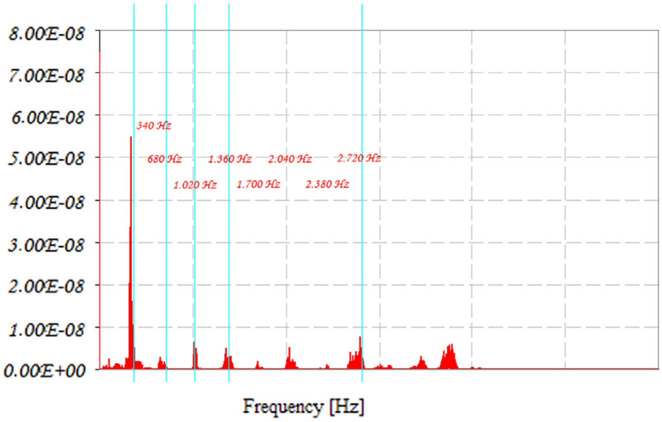

Fig. 4. Spectrum of acoustic emissions.